Topographical Anatomy of Radial Nerve and Its Muscular Branches to Triceps

Dissertation submitted for

M.D Anatomy Branch V Degree Examination,

The Tamil Nadu Dr.M.G.R. Medical University

Chennai, Tamil Nadu.

April – 2017

DECLARATION

I hereby declare that the dissertation entitled **"Topographical Anatomy of Radial Nerve and Its Muscular Branches to Triceps"** is a bonafide research work done by me under the supervision of Dr. Bina Isaac, Professor of Anatomy, Christian Medical College, Vellore, in partial fulfillment of the requirements for the MD Anatomy examination (Branch V) of The Tamilnadu Dr. M.G.R. Medical University, Chennai to be held in April 2017.

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MD Anatomy (Branch V)

CERTIFICATE

This is to certify that **"Topographical Anatomy of Radial Nerve and Its Muscular Branches to Triceps"** is a bonafide work of **Dr. P. Mythraeyee** in partial fulfillment of the requirements for the M.D. Anatomy examination (Branch V) of The Tamil Nadu Dr. M.G.R. Medical University to be held in April 2017.

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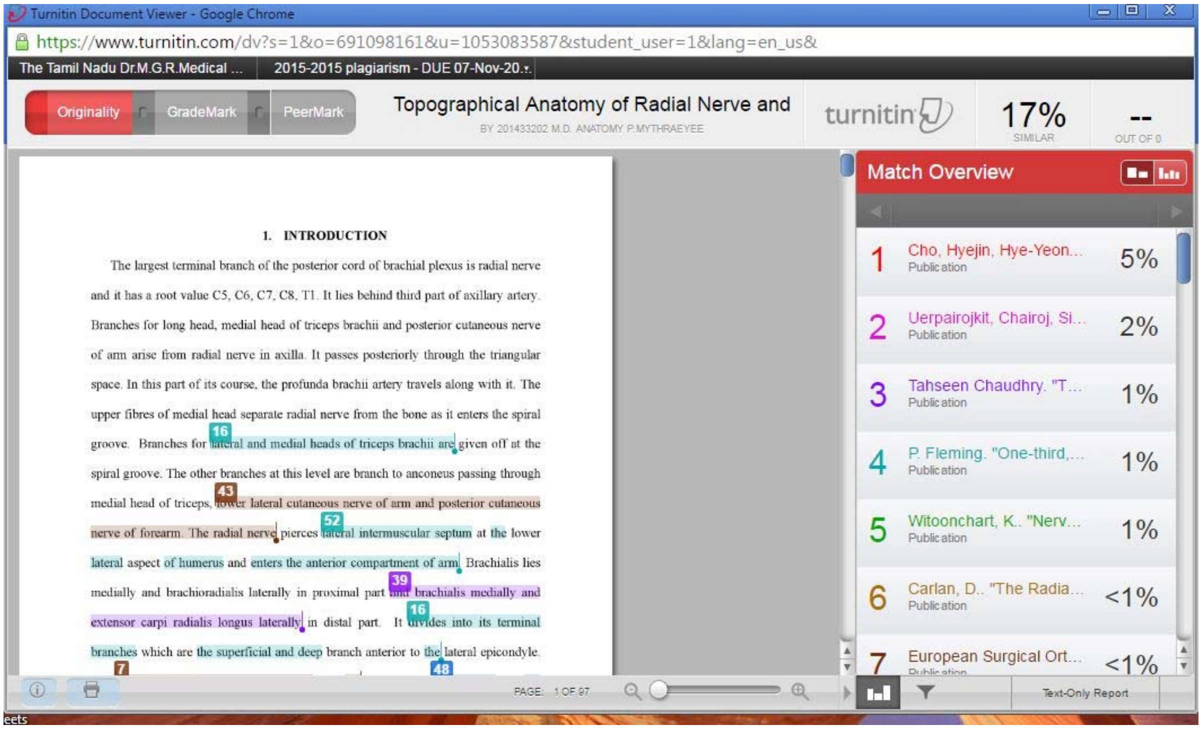
PLAGERISM SCREENSHOT



ACKNOWLEDGEMENTS

- I thank God Almighty for helping me to finish this thesis with His presence in each and every step
- I am grateful to the Institutional Review Board (IRB) of Christian Medical College, Vellore for giving me the permission and funding for this project
- I sincerely thank Dr. Bina Isaac, my guide, for entrusting and encouraging me to start this study and for being an inspiration and support all the time
- Dr. Prasanna Samuel Premkumar, Lecturer, Department of Biostatistics for helping me in calculation of sample size
- Dr. J. Suganthy (Professor and HOD), Department of Anatomy for her support and encouragement throughout the study
- To all Associate Professors and Assistant professors for their help in times of need
- To all co-postgraduates for their valuable suggestions, help and encouragement
- Mr. Balakrishnan and Mr. K. R. Gopi, technicians in the gross anatomy dissection hall for all the help during my dissection work for the thesis
- To all non-teaching staff in the Department of Anatomy –

  Mr. S. Thirumurugan (late), Mr. Antonyswamy, Mr. R. Gopi,

  Mr. Dhandapani, Mr. Babu and Mr. N. Narayanan for their help with arrangement of cadavers and support all the time

- Mr. V. Gopinath (Secretary) and Mr. G. Rajkumar (Artist) in the Department of Anatomy for their timely help
- To all generous volunteers who donated bodies
- Finally I thank all my family members for their constant support, encouragement and prayers

CONTENTS

1. INTRODUCTION

The largest terminal branch of the posterior cord of brachial plexus is radial nerve and it has a root value C5, C6, C7, C8, T1. It lies behind third part of axillary artery. Branches for long head, medial head of triceps brachii and posterior cutaneous nerve of arm arise from radial nerve in axilla. It passes posteriorly through the triangular space. In this part of its course, the profunda brachii artery travels along with it. The upper fibres of medial head separate radial nerve from the bone as it enters the spiral groove. Branches for lateral and medial heads of triceps brachii are given off at the spiral groove. The other branches at this level are branch to anconeus passing through medial head of triceps, lower lateral cutaneous nerve of arm and posterior cutaneous nerve of forearm. The radial nerve pierces lateral intermuscular septum at the lower lateral aspect of humerus and enters the anterior compartment of arm. Brachialis lies medially and brachioradialis laterally in proximal part and brachialis medially and extensor carpi radialis longus laterally in distal part. It divides into its terminal branches which are the superficial and deep branch anterior to the lateral epicondyle. The muscles of posterior compartment of arm are supplied by radial nerve and the muscles of posterior compartment of forearm except brachioradialis and extensor carpi radialis longus are supplied by its deep branch. Cutaneous innervation of lateral surface of dorsum of hand and dorsal surfaces of lateral 31/2 digits excluding their distal dorsal aspects are by superficial branch (1).

The radial nerve is in intimate relation with humerus and hence is highly prone to injury either in humeral shaft or lateral epicondylar fractures. Radial nerve can be affected during treatment following a humeral fracture. An in depth study of the relationship between the humerus and radial nerve (2,3) has been done to prevent such injuries.

Knowledge of the relationship between certain osseous landmarks like the acromion process, deltoid tuberosity, lateral and medial epicondyles and radial nerve can help to prevent injury during intervention following humeral fracture (4). When the osseous elements are displaced due to a comminuted fracture, soft tissue landmarks like the triceps aponeurosis can help to avoid iatrogenic injury during exploratory surgery (5,6).

Nerve transfer is done to restore the function of a paralysed muscle. A detailed knowledge of branches innervating triceps is important for procedures like nerve transfer in lesions of the brachial plexus (7). Intercostal nerve, spinal accessory nerve, contralateral C7 root, and phrenic nerve have been used for nerve transfer. Difficulties encountered in such a procedure were that the donor nerve was far from the nerve of the target muscle and hence a graft was necessary. In C5 and C6 root injuries, nerves like medial pectoral nerve or ulnar nerve were used to restore biceps function (8,9). In the past, shoulder abduction was restored transferring CN XI (spinal accessory nerve) to the suprascapular nerve. This enabled reactivation of the supraspinatus and infraspinatus muscles resulting in 45º of abduction at the shoulder joint and some external rotation. Functional recovery was found to be better when nerve transfer was done for suprascapular nerve and axillary nerves simultaneously (10–12). Deltoid function has been restored by grafting nerve of long head of triceps brachii to axillary nerve (13–15).

The nerve branching pattern to the triceps is complex and there are not many studies on this (19). The purpose of this study was to determine the relationship of the osseous and soft tissue landmarks to radial nerve to prevent intraoperative injury. Innervation pattern of heads of triceps muscle has been studied to find out which branch will be suitable for use in the treatment of upper brachial plexus injuries. There are not many similar studies available in the Indian population. Hence it was decided to undertake this study.

2. AIMS

1. To study the topography of the radial nerve in relation to certain external landmarks.

2. To locate the origin and entry point of radial nerve branches to triceps.

3. To study in detail about motor branches to triceps and to evaluate their possible use as donors for nerve transfer.

3. OBJECTIVES

1. To measure the acromion-transepicondylar distance and to determine as a percentage of this distance the i) point where radial nerve reached and left spiral groove and ii) point where radial nerve pierced lateral intermuscular septum.
2. To measure the distance from midpoint of lateral humeral epicondyle to superior and inferior margins of the spiral groove for radial nerve.
3. To measure the distance from the distal part of deltoid tuberosity to radial nerve.
4. To measure distance between point of confluence and radial nerve.
5. To measure distance from lateral border of triceps aponeurosis to radial nerve.
6. To determine the number of radial nerve branches innervating each head of triceps muscle.
7. To measure the distance from origin of radial nerve branches to each head of triceps brachii and inferior end of deltoid.
8. To measure the distance from entry point of radial nerve branches to each head of triceps brachii and inferior end of deltoid.
9. To measure distance from origin of muscular branch to each head of triceps and inferior border of teres major.
10. To study the patterns of innervation of triceps muscle and to determine the most appropriate branch for nerve transfer.

4. REVIEW OF LITERATURE

Radial nerve is the most commonly involved nerve in fracture shaft of humerus (31). Usage of palpable landmarks to locate the radial nerve can help the surgeon to minimize iatrogenic injury during surgical exposures of the humerus.

Studies to determine the position of radial nerve and its muscular branches to triceps brachii

The course of radial nerve in relation to surface landmarks like the deltoid muscle, epicondyles, and acromion process has been studied in forty upper extremities (7). Externally palpable landmarks are useful to locate the nerve. The mean distance between the acromion and transepicondylar line was found to be 289.5 mm. The radial nerve reached radial groove at 46.7%, left radial groove at 60.5% and pierced lateral intermuscular septum at 66.8% of the mean distance from acromion to transepicondylar line. Radial nerve branches to triceps were studied with regard to their number, origin and entry point. The maximum branches given off from radial nerve were three for long and medial heads and four for lateral head. Branches for long head took origin in axilla and branches for medial and lateral heads arose either in arm or axilla. Branch for long head was given off most proximally whereas branch for lateral head was given off most distally. Origin and entry point of branch for long head was 71.4 mm and 34 mm respectively above inferior end of deltoid. Origin and entry point of branch for medial head was 56 mm above and 16.4 mm below inferior end of deltoid. Origin and entry point of branch for lateral head was 50.7 mm and 19.3 mm respectively above inferior end of deltoid. The division of radial nerve into superficial and deep branch was 5.7 mm proximal with reference to transepicondylar line. The division was above transepicondylar line in 65% of elbows, at transepicondylar line in 2.5% and below transepicondylar line in 32.5% of elbows.

Cox et al. (16) did a similar study to locate the radial nerve using palpable landmarks. They dissected 34 upper limbs. Length of humerus from greater tubercle to lateral epicondyle measured 30.8 cm and length of radius from radial head to radial styloid process measured 24.6 cm. The radial nerve traversed through spiral groove 48% of humeral length, distal to greater tubercle. It pierced lateral intermuscular septum 38% of humeral length, proximal to lateral epicondyle. The division into its terminal branches occurred on average 1.0 cm distal to lateral humeral epicondyle.

Stanescu et al. (17) dissected 33 upper extremities to determine the branching pattern of nerves to triceps brachii. In 88% of specimens, branch to long head arose in axilla and in 9%, branch to medial head arose in axilla. Branches that arose at brachio-axillary angle were 12% for long head, 39% for medial head and 24% for lateral head.In 52% of specimens, branch to medial head was given off at radial groove and in 70%, branch to lateral head was given off at radial groove. In 9%, branches to medial head and in 6%, branches to lateral head arose in axilla. Radial nerve crossed the midline of humerus 3 cm proximal to the insertion of deltoid in 45% of upper extremities. It was found that medial head had an intramuscular tendon. Nerve branches did not cross this tendon from one side to another. Longitudinal splitting of medial head can be done along this tendon to avoid nerve injury.

In order to compare variations of the point of termination of radial nerve between sides of arms, dissection was carried out on eighteen cadavers. Distances from lateral epicondyle to termination of radial nerve and from termination of radial nerve to radial tunnel were determined. Significant differences were found between sides ($p = 0.016$) for the measurement from lateral epicondyle to termination (18).

Radial nerve and the spiral groove

In the study done by Chaudhry et al. (5), the length of the spiral groove was found to be between 29 and 56 mm and there was variation in this finding between the right and left limbs. Muscle fibres separated nerve and bone for most of the spiral groove.

Radial nerve was found to lie in spiral groove 18.1 cm proximal to medial epicondyle and 12.6 cm proximal to lateral epicondyle in a study done by Guse and Ostrum (19). Whereas, Uhl et al. (20) found the distance from the radial nerve in spiral groove to the distal articular surface to be 15.8 in men and 15.2 in women, and in one cadaver, it was 13 cm.

The spiral groove is a region where the radial nerve lies in close contact with bone. It was determined to find out whether there was increased rate of radial nerve injury when there was fracture of humerus at the spiral groove. Fifty-seven dry bones were used for this study by Ozden et al. (3). Distance of spiral groove to proximal and distal landmarks were measured along with the length of humerus. Similar measurements were made on 58 radiographs of patients who had fracture shaft of humerus. Nine of the 24 cases that had a radial nerve palsy had an associated fracture at the spiral groove. It was concluded that there was no increased incidence in lesion of radial nerve when there was a fracture of spiral groove region.

Studies showing relationship of radial nerve with lateral intermuscular septum

Knowing the exact point where the radial nerve is piercing lateral intermuscular septum is useful during the treatment of distal humeral shaft fractures. Fleming et al. (21), did a study on twenty upper extremities. Pins were inserted on the acromion (A) and lateral epicondyle (B). An anterior approach was used. AB was measured. The predicted point (P) was at the junction of proximal two-thirds and distal one third of a line joining acromion to lateral epicondyle. Distance between P and lateral epicondyle (BP) was measured. R is the point where radial nerve traversed the lateral intermuscular septum. Distance of R from lateral epicondyle (BR) was determined. BP – BR was calculated. Radial nerve pierced lateral intermuscular septum within 5mm of the junction of distal and middle thirds of the line joining lateral most point of acromion process of scapula to lateral epicondyle. This method gave accurate results even in individuals of different sizes.

Bono et al. (22) did another study to determine the relationship between radial nerve and lateral intermuscular septum. Measurements were made from the emergence of radial nerve from septum to a number of bony landmarks like superior aspect of the humeral head, surgical neck of humerus, upper margin of olecranon fossa and distal extent of the trochlea. A posterior approach was used. Conclusions drawn were that the nerve crossed the septum, 17 ± 2.3cm from the superior aspect of the humeral head, 12 ± 2.3 cm from the olecranon fossa and 16 ± 0.4 cm from the distal extent of the trochlea. Tethering of radial nerve was seen at the region where it pierced the lateral intermuscular septum. Neuropraxia because of tethering occurs in some distal humeral shaft fractures like the Holstein-Lewis fracture (23). A prediction of the position of radial nerve prior to surgery can prevent injury to the nerve when metal plates and screws are inserted for the fixation of distal end fractures.

A posterior approach is used to treat fractures of lower end of humerus. An osteotomy of olecranon process with elevation of the distal part of the triceps is done if the fracture involves the joint. If the fracture does not involve the joint, a triceps-splitting approach is performed. In both surgeries, the radial nerve can be injured, if the incision is extended far too proximally. Uhl et al (20) exposed the humerus from the posterior aspect in 75 cadaveric upper extremities. They made the exposure as it was done in surgery. Distance from the region where radial nerve pierced lateral intermuscular septum to articular surface (distal) was measured. It was 10.0 ± 1.2 cm in men and 9.4 ± 1.0 cm in women and it reached as close as 7.5 cm in some cadavers.

Tubbs et al.(24) dissected upper extremities of 25 cadavers and did a detailed study of lateral intermuscular septum. The deep and posterior portion of deltoid tendon blended with superior aspect of lateral intermuscular septum. The average thickness of lateral intermuscular septum was 1.0 mm. Lower end of septum had an attachment to lateral humeral epicondyle and merged with annular ligament of head of radius and capsule of elbow joint. The radial nerve passed through an opening of 1 cm in the septum. This information is useful during surgical exploration in this region, especially in cases of entrapment.

Humeral shaft fractures and radial nerve palsy

3% to 5% of fractures are fractures shaft of humerus (31). Such fractures frequently involve radial nerve (25,26). Chances of causing injuries of radial nerve are equal in fractures of the middle and distal part of the shaft of humerus (27). But Pollock et al. (28) found that injuries of radial nerve were more common with fractures in the middle third and on the other hand, Garcia and Maeck (29) found that injuries were more often with fractures of distal third.

Radial nerve palsies most commonly occur with spiral fracture of humerus. It can also occur with transverse and oblique fractures (27–29). There are primary and secondary nerve palsies. 11.8% of palsies are primary and occur at the time of injury(2). Palsies that develop during treatment are referred to as secondary palsies (10% to 20%) (34,37). Primary radial nerve palsies in patients with closed humeral shaft fractures have about 70% spontaneous recovery rate (29–31). Open fractures of humerus can lead to laceration of radial nerve. Radial nerve should be explored early(within the first 2 weeks) in open fractures and in vascular injury (28,32,33).

Injuries that the radial nerve incurs during surgery requires careful attention. Injury rates as high as 20% have been reported after primary open reduction and internal fixation (34–40). External fixation can also cause injury to the radial nerve (41–44). Iatrogenic injuries can occur because of the difficulty of dissecting through the external traumatized soft tissue. Fat present in an obese arm can add to the difficulty in dissection. The rate of iatrogenic injury might be due to the difficulty of applying current anatomic data derived from cadaveric studies to the clinical setting.

Studies suggesting methods to prevent intraoperative injury to radial nerve

Approaches for exploring radial nerve can be anterior, posterior, lateral, modified posterior and anterolateral (45). The radial nerve is prone to injury in each of these approaches (46). Osseous structures can be used to locate the radial nerve but the disadvantage is osseous landmarks can be displaced due to comminuted fractures and humeral malunion/nonunion. It is imperative to identify the radial nerve and protect it during surgery.

i)Relationship of the triceps tendon to the radial nerve

Hasan et al. (47) did a study to identify anatomic landmarks by which intraoperative injury to the radial nerve could be avoided. Thirty three fresh frozen cadavers were chosen for the study so that the measurements made were as close to the living. The lateral epicondyle, proximal part of olecranon fossa, and proximal part of triceps tendon (PATT), were the landmarks used. The mean length of humerus from the acromion angle to the lateral epicondyle was 30.3 ± 18.7cm. As the nerve entered the anterior compartment, it was initially tethered to the lateral humeral shaft for several centimeters by the oblique orientation of the septum. Radial nerve was on an average 2.3cm ± 1.7 proximal to proximal part of the triceps tendon (PATT). It was right at the level of the PATT in three specimens (0.2 cm proximal). In none of the specimens was the nerve found at a point distal to the PATT. The average distance from the proximal most part of olecranon fossa to radial nerve on posterior humeral shaft was 12.9 ±1.1 cm. The proximal part of the triceps tendon is a useful landmark to locate the radial nerve intraoperatively, when the approach is posterior.

ii)Confluence point and the radial nerve

To identify radial nerve during surgery, Seigerman et al. (48) studied 30 fresh frozen upper extremities. The approach was posterior. The upper extremity was positioned as during surgery. Long head, lateral head and aponeurosis of triceps met at point A (confluence point). Point B was where the radial nerve lay on the humerus (Fig. 1). It was found that radial nerve lay 39 ± 2.1 mm proximal to confluence point. This point of confluence is a valuable reference point in the triceps splitting approach.

iii) Radial nerve and aponeurosis of triceps

The position of radial nerve is variable in relation to lateral humeral epicondyle but there is consistent relationship of the radial nerve to triceps aponeurosis. This can be taken into consideration by the surgeon while doing surgery for fractures of the mid-third and distal third of the humerus. The triceps aponeurosisis an easily recognizable structure during surgery. Chaudhry et al. (5) did a study on 55 upper extremities. Four equally spaced points were marked along the lateral border of triceps aponeurosis. Distance between these points and radial nerve were measured. They found that the radial nerve passed consistently at a distance of 22 – 27 (±2) mm from triceps aponeurosis. The nearest distance between aponeurosis and nerve was 13 (±1) mm. Hence, exploratory surgery in an area < 10 mm from the triceps aponeurosis was safe and will prevent intraoperative injury. The aponeurosis was in its distal end parallel to the humerus but in its proximal one fourth curved medially and blended with muscle fibres.

A study to determine proximity between radial nerve and apex of aponeurosis of triceps was carried out on 10 upper extremities and 60 cases (patients - 30 and control patients - 30) by Arora et al. (6). Open reduction and internal fixation for fractures of distal third of humerus were performed on these patients. A posterior approach was used. The surgery in the control group was done in the usual conventional manner. The surgeons operating on the control group did not know how radial nerve and apex of aponeurosis of triceps was related. Distance of radial nerve from apex of aponeurosis of triceps was 2.5 cm. The value was the same in cadavers and patients. Origins of long and lateral head of triceps are well above the distal third of humerus. Hence, the apex of triceps aponeurosis will remain undisturbed even when there is discontinuity of bone distal to it. None of the patients showed signs of postoperative radial nerve palsy, but three among the control group developed palsy.

iv)Zone of vulnerability on the humeral shaft

Hasan et al.(47) have found a zone on the brachium called the 'zone of vulnerability, where the radial nerve is likely to get injured as it runs along the lateral humeral cortex. A length of 6.7 ± 1.4 cm of radial nerve lay directly on the humeral periosteum. Out of this, 4.6 ± 0.9 cm lay on the humeral posterior cortex and 2.1 ± 1.0 cm on the lateral cortex, just before travelling through lateral intermuscular septum. Mean distance from centre of lateral epicondyle to the point where radial nerve traverses lateral intermuscular septum was 11.2 ± 2.1 cm. There is tethering of radial nerve for several centimeters along the lateral cortex after passing through septum. This increases the vulnerability of nerve to injury. Knowledge of this "zone of vulnerability," especially while performing a lateral approach to the humerus, might help avoid iatrogenic injury. The presence of such a zone should be kept in mind while making limited incisions in the lower part of the lateral humeral cortex for applying external fixator pins.

v)Prevention of injury to the radial nerve during an anterior approach to the humerus

Carlan et al. (49) did a study to determine relationship of radial nerve to the posterior and lateral aspects of humerus. This study is useful during intervention procedures in midshaft and distal humerus. Dissection was carried out on 27 adult specimens of cadavers, out of which 18 were embalmed and 9 were fresh frozen limbs. It was found that 6.3 cm ± 1.7 of nerve lay on periosteum of humerus without muscle fibres or fascia separating nerve from bone. There was no structural radial groove seen in all the specimens studied. There are two areas where radial nerve can get injured during fixation for humeral fracture. Radial nerve was found at a distance of 0.1 cm ± 0.2 on the posterior midline of humerus from distal aspect of tuberosity of deltoid. The tuberosity of deltoid can be used as a reliable landmark to avoid radial nerve injury while repairing humerus using an anterior approach. The second area is on the lateral aspect of the distal third of the humerus which was 10.9 cm ± 1.5 proximal to lateral humeral epicondyle. There is tethering of radial nerve after passing through lateral intermuscular septum. Hence, the mobility of the nerve is reduced in this region. Palpable landmarks such as the deltoid tuberosity and lateral humeral epicondyle can be used to determine the location of radial nerve during surgery.

vi)Prevention of radial nerve injury during posterior approach to humerus

Gerwin et al. (50) did a study to determine the amount of exposure of humerus got in three posterior approaches. Ten upper limbs were dissected for this study. Radial nerve was found at a distance of 20.7 ± 1.2 cm proximal to medial epicondyle and

14.2 ± 0.6 cm proximal to lateral epicondyle. Branches were given to lateral head, on reaching posterior surface of humerus. Subsequently, as radial nerve reached the lateral aspect of humerus, branches to medial head and lower lateral cutaneous nerve of arm were given off. Three operative approaches were performed in each specimen. The first approach (triceps splitting approach) exposed humerus with a mean distance of 15.4 ± 0.8 cm from lateral humeral epicondyle to the point where radial nerve crossed the posterior surface of the humerus. Second approach - an additional six cm of the humeral diaphysis was visualised by mobilising the radial nerve proximally. Third approach (modified posterior approach) - Lateral head and medial heads of triceps were reflected medially. Greater visualization of about 26.2 ± 0.4 cm of the humeral shaft measured from the lateral humeral epicondyle proximally was possible with this approach. Knowing where the radial nerve is located with respect to lateral epicondyle and the amount of exposure obtained can help the surgeon to decide on the operative approach needed.

Recovery time of patients with fracture shaft of humerus along with radial nerve palsy is longer than patients with fracture alone. A study on 44 cases of acute humeral shaft fractures treated with plate fixation, 97% healed within 12 weeks time. Twelve of the 15 patients who had associated radial nerve palsy, recovered in 17 weeks time (51).

Studies on Nerve transfer

Nerve transfer involves sectioning a normal nerve and connecting its end to a nerve which has been injured. Donor nerve function would be compensated by other neighbouring muscles with intact innervation. A nerve which is in close proximity to the target muscle is preferred to reduce the time for recovery. There are a number of procedures for nerve transfer used in cases of brachial plexus injury (57).

Axillary nerve injury can occur in dislocation of shoulder, or intraoperatively as a part of surgery involving shoulder region or as a part of brachial plexus palsy (52–54). Axillary nerve injury can lead to weakness of movements at the shoulder joint like abduction and external rotation of arm (52).

The long head branch of triceps was used for transfer to axillary nerve by Coleman in 1946. Triceps fascicles were transferred to axillary nerve (13,55,56) using an approach which is posterior. Similar results were obtained by transferring the branch of lateral head of triceps to axillary nerve (56)

Restoring the function of deltoid muscle by nerve transfer

Bertelli et al. (57) did a study to find which of the branches to triceps could be used for nerve transfer. Ten arms were used for this study. Number of nerves innervating triceps was one branch for long head and two branches each for the lateral and medial heads. Branch for upper part of lateral head originated from radial nerve and branch for lower part of lateral head arose from the branch to lower part of medial head. Upper and lower parts of medial head were each supplied by a separate branch. Anconeus muscle was supplied by the branch to lower part of medial head. Since, branches for long head of triceps brachii and upper part of medial head arose in axilla, these branches can be used for transfer to axillary nerve through an axillary approach. The diameter of the branch to long head of triceps brachii is large, but usage of this branch can completely denervate that head, as it had a single innervation. The branch to upper part of medial head can be used completely as there were two branches for medial head. Branches for long head and upper part of medial head can be used for transfer using a posterior approach also, since no cutaneous nerves are related to them. Another branch that could be used for transfer to axillary nerve is branch for upper part of lateral head, but care should be taken that no cutaneous nerves arise from it. This can be done using a posterior approach. Lateral head is not denervated, as it had another branch supplying the lower part. The branch for lower part of medial head has a greater length than the other branches allowing for coaptation of nerve to deltoid motor branch very near to the muscle. They concluded that each of the branches to triceps can be considered as suitable donor nerves. In the case of upper brachial plexus injury with intact triceps function, it is better to transfer the branch for long head or upper part of medial head to axillary nerve, using an axillary approach. In the event where the triceps is paralyzed partially, the branches to lateral head of triceps and not long head should be used, since the lateral head has double innervation. For reconstruction of triceps function, the long head of triceps should be reinnervated, as its origin from the glenoid cavity makes it useful for shoulder stabilization .

The axillary nerve has been repaired using a posterior or deltopectoral approach. Bertelli et al. (57) wanted to find out whether the axillary nerve could be visualized and repaired via an axillary approach, where branches of axillary nerve as well as the trunk of the nerve could be seen easily. In this, the motor branch of the long head of triceps was coapted to the axillary nerve branches supplying deltoid and teres minor. Ten upper extremities were used for this study. This axillary approach is good when the long head branch is used for transfer as it originated proximally in axilla. Three patients underwent repair of axillary nerve using axillary approach. At the follow up which was eighteen months after surgery, all 3 patients had recovery of deltoid strength to a score (M4) and abduction strength was improved by 50%. The elbow extension was good. The triceps function was unaffected because medial head and lateral head of triceps had intact innervation and compensated for long head.

Uerpairojkit et al. (58) did a detailed study on the pattern of nerve supply for triceps to find the appropriate radial nerve branch which can be used for nerve transfer. Radial nerve branches of triceps brachii lie in close proximity to the deltoid, hence these branches are the most suitable for transfer. A nerve graft is not necessary in this case. The study utilised 79 arms. Distances of radial nerve branches from their origin to the lower border of teres major were measured for each head of triceps. Measurements of lengths of these branches was also done. Branch to long head was the first branch in 100% of arms. The second branch was different – it was to the upper part of medial head in 38%, to medial head in 10.1%, upper part of lateral head in 44.3% and to lateral head in 7.6%. The nerve of long head was the nerve of preference for restoring deltoid function as it was could easily reach the anterior branch (axillary nerve) without the use of a nerve graft. Diameters of long head branch and axillary nerve were the same. 7.6% of arms in the study had single branch for lateral head and usage of these nerves for transfer was inadvisable as it would impair the function of triceps. The constant point of origin and proximal location of long head branch in the axilla made it the nerve of choice for anastomosis with axillary nerve.

Wittoonchart et al. and Zhao et al. (14,59) did a study anastomosing the nerve for long head of triceps to anterior branch (axillary nerve) using a posterior approach.

Posterior approach was used, since studies have shown that the nerve fibres were reduced in number when the anterior approach was used. 36 embalmed cadavers and 6 fresh cadavers were used for this study. Length and diameter of the branches for long head and lateral head of triceps were measured at the triangular space. Distances from angle of acromion to the origin of nerve for long and lateral head of triceps and to bifurcation of anterior and posterior branches of axillary nerve were determined. Using long head branch for transfer to axillary nerve results in minimal functional loss. The lateral and medial heads will compensate for the function of long head and it is found that they play a more important role in elbow extension than long head (66). The proximal origin of nerve for long head makes it suitable for direct nerve transfer to anterior division (axillary nerve). Advantages of this procedure - deltoid function was restored with the use of a motor nerve, no grafting of nerve was required and diameters of donor and recipient nerves matched.

A study was carried out to determine the number of radial nerve branches supplying each head of triceps and distance of origin of first branch to each head from the humeral head. The study was done by Al-Meshal and Gilbert (60). Dissection was done on twenty-five arms. Long head had one branch in 92% and two branches in 8%. The first branch arose at a distance of 2 - 10 cm from the humeral head. Medial head had single branch in 88% and double branches in 12%. The first branch for medial head arose at a distance of 5 -15 cm from the head of humerus. Lateral head was the thickest head and had 2 or more branches in all cases (100%). The first branch for lateral head took origin at a distance of 4 - 12 cm from head of humerus. The long head had single innervation in 92% of cases and hence its branch was unsuitable for nerve transfer. The most proximal branch for lateral head of triceps seemed to be the most suitable branch that could be used to restore functionality to deltoid muscle and the lateral head will not be denervated, as it received more than one branch.

Combined nerve transfers

Colbert and Mackinnon (61) tried to restore shoulder function by transferring two nerves, instead of one to restore deltoid function. Radial nerve (C5, C6, C7, C8, T1) is less affected than axillary nerve (C5,C6) in injuries of brachial plexus, as it is composed of more number of nerve roots. They anastomosed spinal accessory nerve to suprascapular nerve and nerve of medial head to axillary nerve, proximal to its branch supplying teres minor. A posterior approach was used. The branch of medial head of triceps is easier to expose compared to the branches to the long and lateral heads. Branch of medial head has a long length and it is easily identified as it lies superficial between long and lateral heads. Dissection into muscle may be required to obtain branches of long and lateral heads. The ease of identification and increased length of medial head branch make it an appropriate donor. Reinnervating the teres minor along with deltoid provide better shoulder stability in axillary nerve reconstruction.

Combination of nerve root grafting and nerve transfer

It was found out by Bertelli and Ghizoni (56) that in the treatment of upper brachial plexus injuries, distal multiple nerve transfers done along with nerve root grafting provided a better outcome. Grafting of the nerve roots would enable reinnervation of the antagonist and stabilizer muscles of the shoulder girdle. Thirty seven patients who had C5-C6 injury were taken for the study. The injury resulted in weakness of shoulder abduction, flexion of elbow and supination of forearm. Surgery was performed a little over six months following trauma. Seven patients who had avulsed C5 and C6 roots, triple nerve transfer was done (accessory nerve to suprascapular nerve, ulnar nerve fascicles to biceps motor branch, and triceps branches to axillary nerve and the teres minor motor branch). Twenty four patients who had rupture of C5 nerve root as well as avulsion of C6 root, triple nerve transfer along with grafting of C5 root to anterior division of upper trunk was done. Six patients who had rupture of C5 and C6 roots, anterior division and posterior division of upper trunk were grafted with anterior and posterior portions of C5 and C6 roots along with accessory nerve transfer to suprascapular nerve, and ulnar nerve fascicles to biceps motor branch. Good recovery was seen in patients who underwent reconstruction with both nerve transfers and nerve root grafting.

Pattern of branching of the nerves to triceps

The pattern of branching of the nerves to triceps was studied and classified into five types depending on the number of branches as A, B, C, D by Uerpairojkit et al (58) (Fig. 10). Type A (five branches) was seen in 26.6%. Branches were – one to long head, one to upper part of medial head, one to lower part of medial head, one to upper part of lateral head and one to lower part of lateral head.

Type B (four branches) was seen in 48.1%. Under type B, there was type B1 (21.5 %) and type B2 (27.8%). In B1, there were 2 groups. In the first group (B1 – 1st pattern), there were two branches to lateral head (10 arms) and in the second group (B1 – 2nd pattern), there were two branches to medial head (7 arms). In B2, there was one common branch, either to medial or lateral head. The common branch presented 5 different patterns as follows –

B2- 1st pattern (9 arms) – common branch supplying upper and lower parts of medial head

B2- 2nd pattern (2 arms) – common branch supplying upper and lower parts of lateral head

B2- 3rd pattern (3 arms) – common branch supplying upper parts of medial and lateral heads

B2- 4th pattern (5 arms) – common branch supplying lower parts of medial and lateral heads

B2- 5th pattern (2 arms) – common branch supplying lower part of medial head and upper part of lateral head

Type C (three branches) was seen in 21.5%. The categories under type C were C1, C2, C3 and C variations.

C1 pattern – three branches with a common branch to lateral or medial head

If common branch was to lateral head, the branches from the common trunk were to upper and lower parts of lateral head (5 arms)

If common branch was to medial head, the branches from the common trunk were to upper and lower parts of medial head (2 arms)

C2 pattern– two common branches were seen (5 arms)

One common branch supplying upper and lower parts of lateral head

One common branch supplying upper and lower parts of medial head

C3 pattern – three branches with no common branch (2 arms)

C variations

C variations – branches to upper and lower parts of medial head were from the branch to upper part of lateral head (2 arms)

C variations – branches to upper and lower parts of medial head were from the branch to long head (1 arm)

Type D (2 branches) was seen in 3.8%

One branch to long head and one common trunk supplying upper part of lateral head, lower part of lateral head, upper part of medial head and lower part of medial head (3 arms)

This study helped to identify the nerve which is most suitable for transfer.

5. MATERIALS AND METHODS

This study was done after approval from the Institutional review board (IRB) and Ethics Committee. A total of 28 arms from 14 formalin embalmed adult cadavers (10 male and 4 female) aged between 44 – 90 years available in the Department of Anatomy, Christian Medical College, Vellore were taken for this study. Upper extremities having gross malformation, deformities or severe injuries were excluded from the study.

Dissection was done using a scalpel, a toothed forceps, a non-toothed forceps, a scissors, coloured pins, white thread, cotton and a bowl of water. All measurements were carried out by one observer while the other observer recorded the results. Measurements were done by means of a Sliding Digital Vernier Caliper (ROBUST, Germany), with a resolution of 0.01mm and an inch tape.

<u>Sample size calculation</u>

A total of 28 cadavers will be required to estimate the mean distance from the acromion to the transepicondylar to be within ± 7 mm and with 95% confidence intervals. The standard deviation (SD) was assumed to be 18.7 (4).The following formula was used for the calculation of sample size:

$$n = \frac{{Z_{1-\frac{\alpha}{2}}}^2 (SD)^2}{d^2}$$

where n - number of cadavers needed, $\left(Z_{1-\frac{\alpha}{2}}\right)$ - is the standard normal variate, SD - standard deviation and d - desired precision.

Topographical anatomy of radial nerve

Understanding the topographical anatomy of radial nerve is important in the treatment of fracture of humerus and upper extremity function restoration. The lateral epicondyle and acromion process were used as they were easy palpable surface landmarks. The distance between tip of acromion and lateral humeral epicondyle was measured and relationship of radial nerve to this distance was used to delineate the position of the radial nerve before exploratory surgery was undertaken.

Prevention of intraoperative injury to radial nerve

Certain anatomical markings are easily identifiable intraoperatively – distal part of deltoid tuberosity, point of confluence and lateral border of triceps aponeurosis. Using these markings, intraoperative injury to the radial nerve can be avoided.

Measurements done to locate the radial nerve intraoperatively

- Distance between distal part of deltoid tuberosity and radial nerve at posterior midline of humerus
- Distance between confluence point (meeting point of long head, lateral head and triceps aponeurosis) and radial nerve
- Distance between aponeurosis of triceps and the radial nerve

For procedures like nerve transfer

The muscular branches of radial nerve are used as donor nerve or recipient nerve in nerve transfer procedures for restoring the action of upper limb muscles. The branches of triceps can be anastomosed with axillary nerve in cases of C5-C6 root injuries, for restoring the action of deltoid muscle. In order to find the branch which will be the most suitable one for nerve transfer, the following observations were made.

- Number of radial nerve branches supplying each head of triceps
- Distance of radial nerve branches to triceps from muscles like teres major and deltoid
- Distance of first radial nerve branch from teres major. The proximity of this branch to anterior branch (axillary nerve) makes it suitable for transferring to axillary nerve without a nerve graft
- Innervation (single/double) of medial head of triceps brachii. In case of double innervation, one of the branches could be used for transfer.
- Patterns of branching of radial nerve to triceps brachii

Method of dissection

The cadaver was placed in a prone position on the dissection table. Both arms were extended, placed on arm boards and tightly fastened to the boards. The degree of extension at the elbow was fixed. The palpable bony landmarks like tip of acromion, the medial humeral epicondyle and lateral humeral epicondyle were identified. A longitudinal incision was made from the tip of acromion to the superior aspect of the olecranon process of ulna. A transverse incision was made at the proximal end of this longitudinal incision at the level of tip of acromion. Another transverse incision was made at the distal end of this longitudinal incision at the olecranon process level. The skin flaps on the posterior surface of the arm were reflected. The superficial fascia containing cutaneous vessels, cutaneous nerves and fat were removed. This exposed the deep fascia investing the triceps brachii muscle.

The deep fascia was cleaned. Long head, lateral head and aponeurosis of triceps were identified. Coloured pins were used to mark tip of acromion, medial humeral epicondyle and lateral humeral epicondyle. A white thread was used to mark the transepicondylar line. The long head and lateral head were identified and separated by making a superficial cut vertically at the place where they are in close contact. Radial nerve was identified along with profunda brachii artery in spiral groove. The superior margin of spiral groove and location of entry of radial nerve into spiral groove were identified and marked with a coloured pin. The inferior margin of spiral groove and the location of exit of radial nerve from spiral groove were also identified and marked with a coloured pin. The further radial nerve course was followed up from inferior margin of spiral groove to the location where it pierced lateral intermuscular septum, by cutting across the middle of lateral head of triceps, all the time keeping its nerve branches intact. The location where radial nerve is piercing lateral intermuscular septum was identified and marked with a coloured pin. The radial nerve course was followed from lateral intermuscular septum distally till it entered the anterior compartment of the arm. The radial nerve in distal part of arm was found lying at first between brachialis and brachioradialis muscles and then between brachialis and extensor carpi radialis longus muscles. The radial nerve terminated at lateral humeral epicondyle and this point of termination of radial nerve was marked with a coloured pin. Coloured pins were used to mark the deltoid tuberosity and the point where radial nerve lay on midline of posterior aspect of humerus. Using an inch tape, the following measurements were made

- distance between tip of acromion and transepicondylar line
- point where radial nerve reached and left the spiral groove
- point where lateral intermuscular septum was pierced by radial nerve
- point where radial nerve divided into its terminal branches namely the superficial and deep branches
- distance from distal part of deltoid tuberosity to radial nerve at midline of posterior aspect of humerus

The location of termination of radial nerve was noted as above/at/below the transepicondylar line of humerus. The percentage of arms at each of these three levels was calculated.

The Confluence point and radial nerve

The confluence point of long head, lateral head and aponeurosis of triceps was identified and marked with a coloured pin. The distance between the confluence point to radial nerve on midline of posterior surface of humerus was measured (Fig. 1).

Radial nerve measurements in relation to aponeurosis of triceps

The arm, elbow and the forearm were maintained in prone position with the elbow extended. The lateral border of aponeurosis of triceps and midpoint of lateral humeral epicondyle were found and marked with a coloured pin. The distal part of radial nerve after its emergence from lateral intermuscular septum was related to lateral border of aponeurosis of triceps. The triceps aponeurosis was divided into four equal parts in a distal-proximal manner as 1/4, 2/4, 3/4, 4/4 with coloured pins. These parts are indicated by D, E, F, and G (Fig. 2).Then the following measurements were made as shown in the diagram:

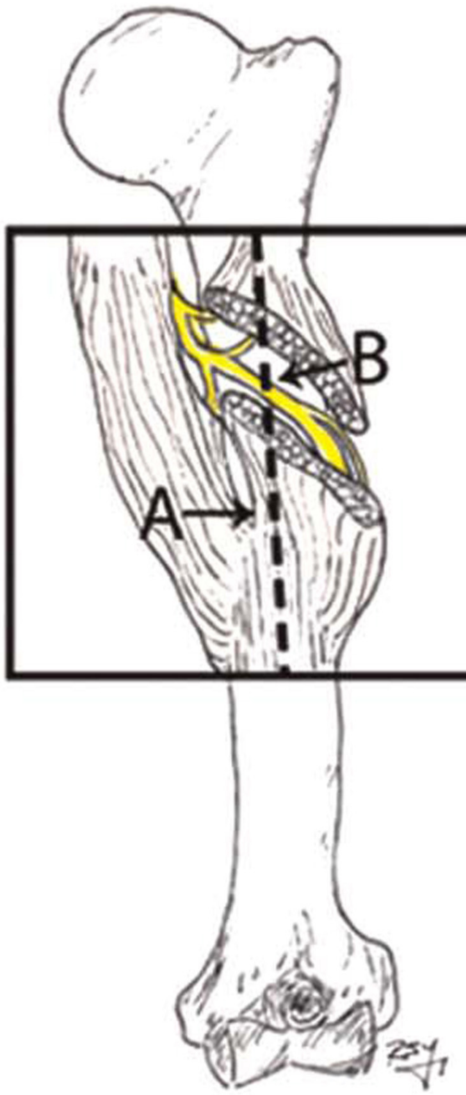


Fig. 1 . Measurement taken from Point A (point of confluence) to Point B (radial nerve at the midaxial posterior humerus)

Line diagram ref: Identification of the Radial Nerve During the Posterior Approach to the Humerus: A Cadaveric Study by Seigerman et al. (2012)

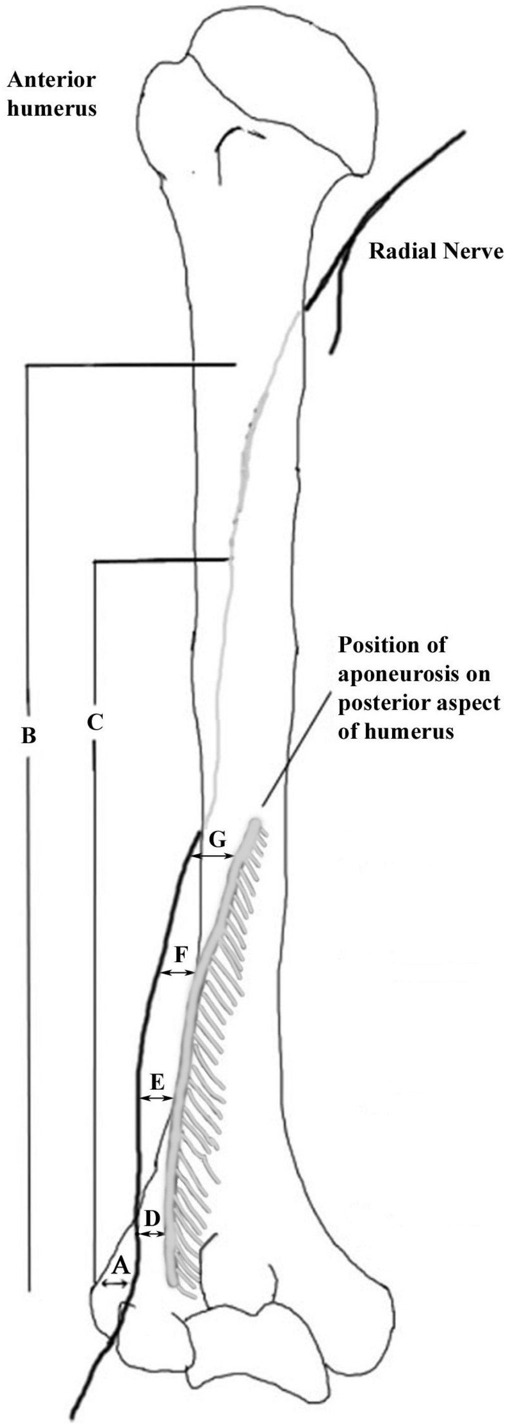


Fig . 2 . Measurements of the Radial Nerve in relation to the Triceps Aponeurosis

A - Shortest distance of nerve to lateral epicondyle
B - Lateral epicondyle to superior margin of groove
C - Lateral epicondyle to inferior margin of groove
D - Aponeurosis 1/4 to nerve
E - Aponeurosis 2/4 to nerve
F - Aponeurosis 3/4 to nerve
G - Aponeurosis 4/4 to nerve

Line diagram ref: The surgical Anatomy of the Radial Nerve and the Triceps Aponeurosis by Chaudhry et al. (2010)

A - the shortest distance of radial nerve to lateral humeral epicondyle

B - lateral humeral epicondyle to superior margin of the spiral groove

C - lateral humeral epicondyle to inferior margin of the spiral groove

D - the distance between 1/4 aponeurosis of triceps to radial nerve

E - the distance between 2/4 aponeurosis of triceps to radial nerve

F - the distance between 3/4 aponeurosis of tricepsto radial nerve

G- the distance between 4/4 aponeurosis of triceps to radial nerve

Measurements of radial nerve branches to long head, lateral head and medial head of triceps brachii

Deltoid tuberosity was marked with a coloured pin and the reference level of the deltoid insertion was indicated by using a white thread extending horizontally across the posterior surface of the arm from the coloured pin. The inferior border of teres major was identified and marked with a coloured pin. Radial nerve branches to the long, lateral and medial heads of triceps brachii were identified, and the number and origin of these branches were studied. The distances from level of inferior end of deltoid to origin and entry point of nerve branch were measured. The distance between the origin of branches and inferior border of teres major was also measured.

The pattern of innervation for medial head (single/double) was studied.

Pattern of branching

The pattern of nerve branching to triceps brachii was studied and classified according to the classification pattern suggested by Uerpairojkit et al. (58). Type A - 5 branches, type B – 4 branches, type C – 3 branches and type D – 2 branches (Fig.10).

Data analysis

The data was entered into Excel worksheet (Microsoft Office Excel; version 2010) and analysed using SPSS (version 16.0). The measurements made were compared between the side of the specimen using paired t-test. $P < 0.05$ was considered to be significant.

6. RESULTS

6.1 Variables to trace Radial Nerve course

The following variables were taken into account to trace the radial nerve course in relation to bony landmarks like tip of acromion, medial humeral epicondyle and lateral humeral epicondyle. The values obtained are shown in Table1.

Table 1. Measurements to trace Radial Nerve course

Parameter	Mean distance (mm)	SD (mm)	Range (mm)
Distance between tip of acromion and transepicondylar line	268.1	28	220-358
Distance between tip of acromion and point where radial nerve entered spiral groove	109.4	24.4	75-180
Distance between tip of acromion and point where radial nerve left spiral groove	146.8	25.7	98-196
Distance between tip of acromion and point where radial nerve pierced lateral intermuscular septum	180.2	30.3	124-248
Distance between transepicondylar line and site of termination of radial nerve	24.7	8.8	10-45
Distance from distal part of deltoid tuberosity and radial nerve at posterior midline of humerus	37.6	13	20-78

The mean, standard deviation, and the range shown are for both right and left arms taken together.

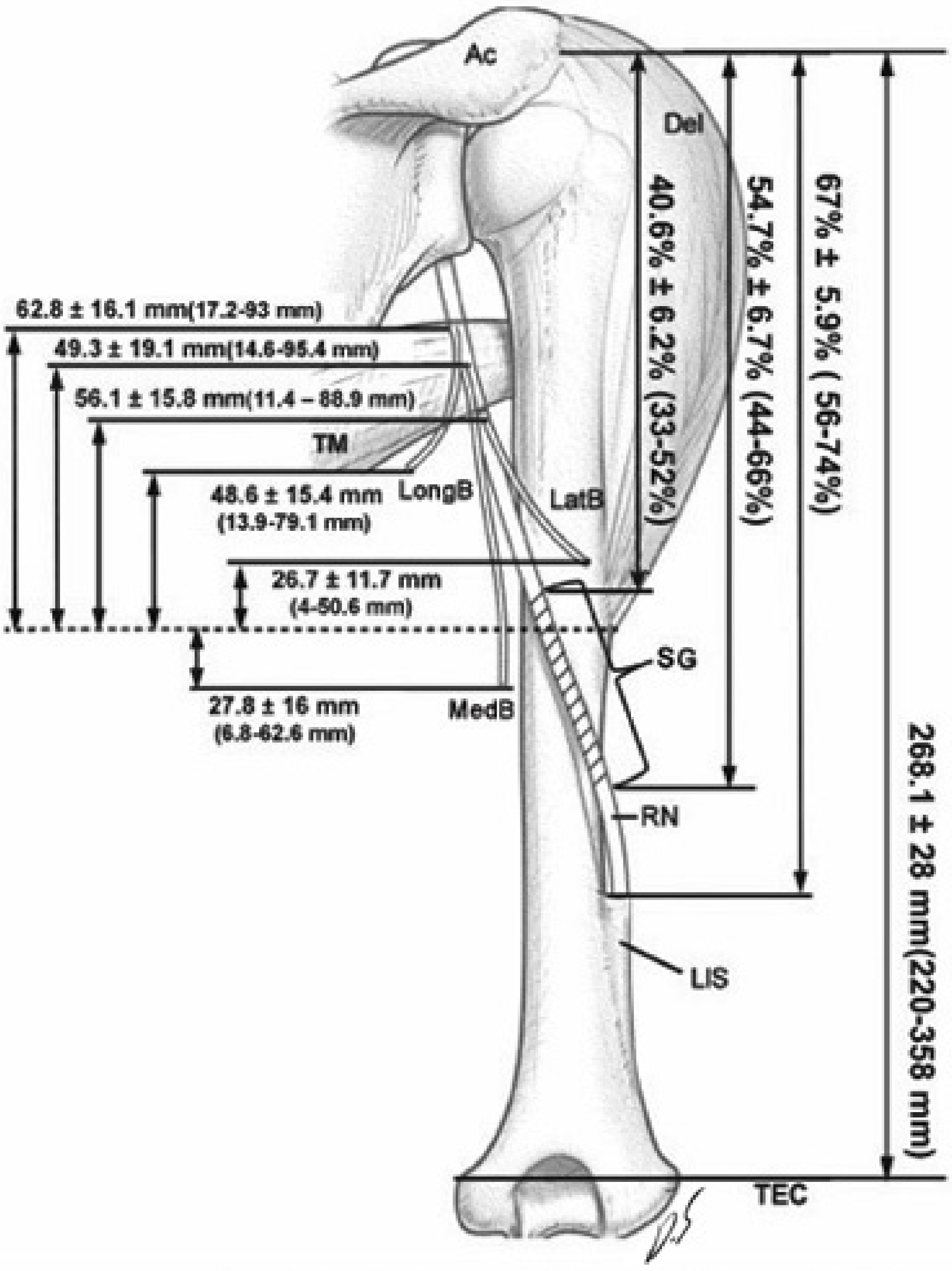


Fig . 3 . The course of the radial nerve (RN) and the location of the branches to each head of the triceps brachii

The left side of the figure shows the distances between the inferior end (dotted line) of deltoid muscle (Del) and the origin and attachment of the branches to the triceps brachii.

The right side of the figure shows the RN reaching and leaving the spiral groove (SG) and piercing the lateral intermuscular septum (LIS). The distances are shown as a proportion of the distance between the acromial tip and transepicondylar line (TEC).

Ac, acromion; LatB, branch to lateral head; MedB, branch to medial head; LongB, branch to long head; TM, teres major

Line diagram ref: Topographical Anatomy of the Radial Nerve and Its Muscular Branches Related to Surface Landmarks by Cho et al. (2013)

Distance between tip of acromion and transepicondylar line

The mean distance between tip of acromion and transepicondylar line was found to be 268.1 ± 28 mm. The minimum distance was found to be 220 mm and the maximum distance was 358 mm (Fig. 3). In males the mean distance was 276 mm and in females, 244 mm.

Distance between tip of acromion and point where radial nerve entered spiral groove

The mean distance between tip of acromion and the point where radial nerve entered spiral groove was found to be 109.4 ± 24.4 mm. The minimum distance was found to be 75 mm and the maximum distance was 180 mm. This distance constituted 40.6% ± 6.2% of line between tip of acromion and transepicondylar line (range, 33% - 52%) (Fig. 3).

Distance between tip of acromion and point where radial nerve left spiral groove

The mean distance between tip of acromion and the site where radial nerve left spiral groove was 146.8 ± 25.7 mm. The minimum distance was found to be 98 mm and the maximum distance was 196 mm. This distance constituted 54.7% ± 6.7% of line between tip of acromion and transepicondylar line (range, 44% - 66%) (Fig. 3).

Distance between tip of acromion and point where radial nerve pierced lateral intermuscular septum

The mean distance between tip of acromion and point where radial nerve pierced lateral intermuscular septum was 180.2 mm ± 30.3 mm. The minimum distance was found to be 124 mm and the maximum was 248 mm. This distance constituted 67% ±

5.9% of line between tip of acromion and transepicondylar line (range, 56% - 74%) (Fig. 3).

Distance between transepicondylar line and site of termination of radial nerve

The mean distance between transepicondylar line and site of termination of radial nerve was 24.7 ± 8.8 mm. The minimum distance was found to be 10 mm and the maximum was 45 mm.

Distance from distal part of deltoid tuberosity and radial nerve at posterior midline of humerus

The mean distance between radial nerve at posterior midline of humerus and distal part of deltoid tuberosity was 37.6 ± 13 mm. The minimum distance was found to be 20 mm and the maximum was 78 mm.

6.2 Radial nerve and its division into terminal branches

The location of division of radial nerve was identified with reference to transepicondylar line as above it/at the same level/below it (Table 2) (Figs. 4 and 5).

Table 2. Location of Radial Nerve division into the terminal branches

Location	(%)
Above transepicondylar line	85.7
At transepicondylar line	0
Below transepicondylar line	14.3

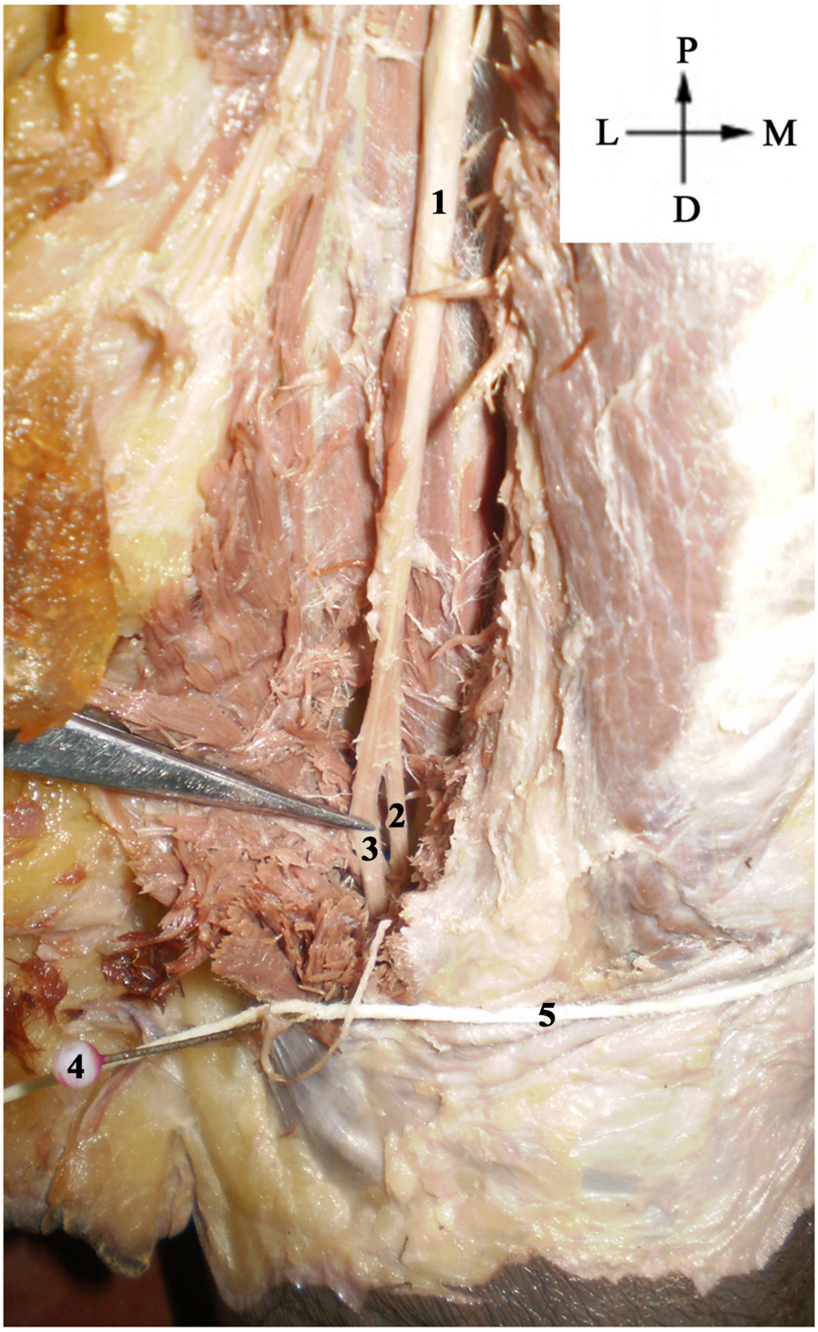


Fig. 4 . Posterior view of the left humerus showing the division of the radial nerve in to its branches above the transepicondylar line.
1 - radial nerve 2 - deep branch 3 - superficial branch 4 - lateral epicondyle
5 - transepicondylar line

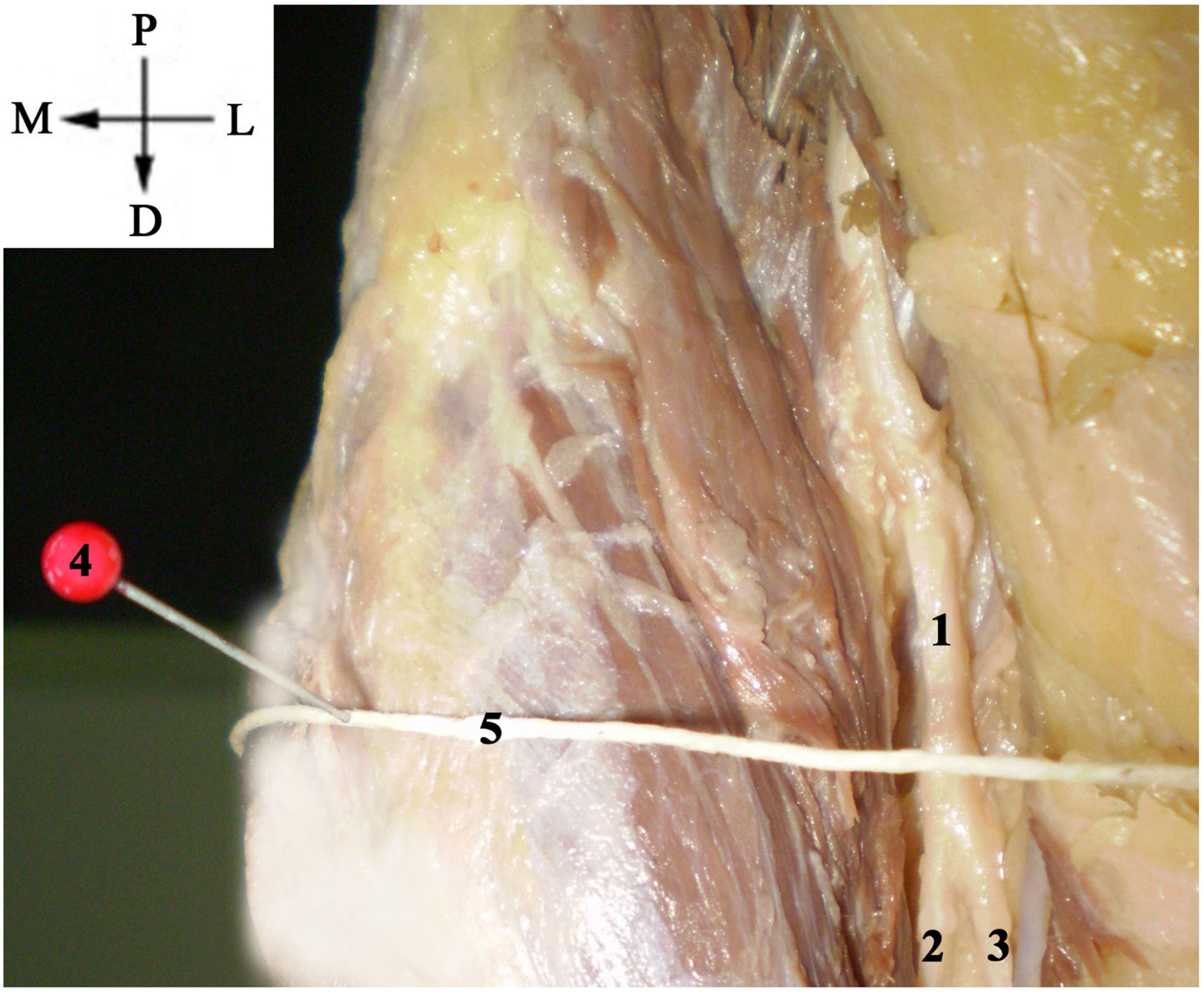


Fig. 5. Posterior view of the right humerus showing the division of the radial nerve in to its branches below the transepicondylar line.
1 - radial nerve; 2 - deep branch; 3 - superficial branch; 4 - lateral epicondyle; 5 - transepicondylar line

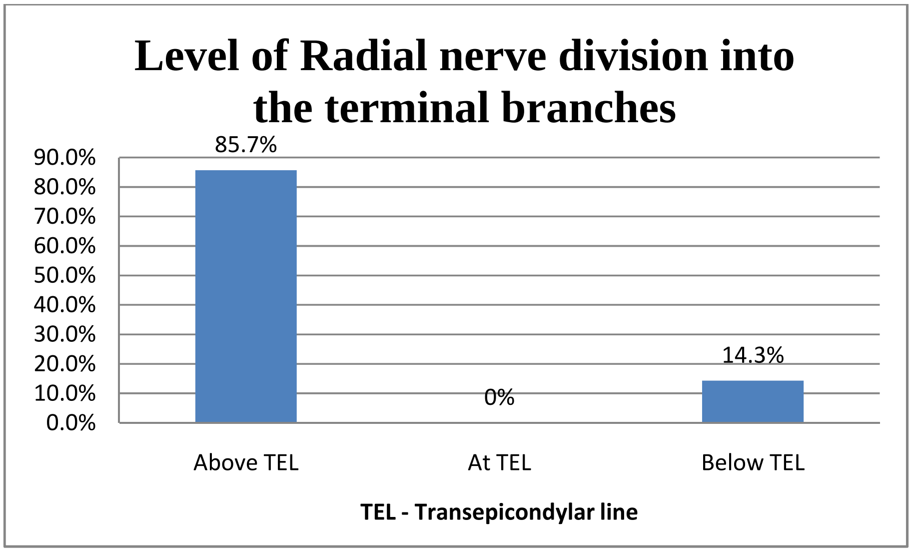


Chart 1. Level of Radial nerve division into the terminal branches

Chart 1, shows that in the majority of upper extremities (85.7%), the level of termination of radial nerve into its terminal branches was above transepicondylar line and in 14.3%, the division was below transepicondylar line. In none of the specimens was the division at the transepicondylar line.

6.3 Confluence point and radial nerve

The Confluence point is the meeting point of the long head, lateral head and aponeurosis of triceps (Fig. 6).

Distance measured between radial nerve and confluence point is shown in Table 3.

Table 3. Distance between the Point of Confluence and Radial Nerve

	Mean distance (mm)	SD (mm)	Range (mm)
Right arm	39.3	11.5	20.1-57.4
Left arm	40.1	12.6	17.1-61.9

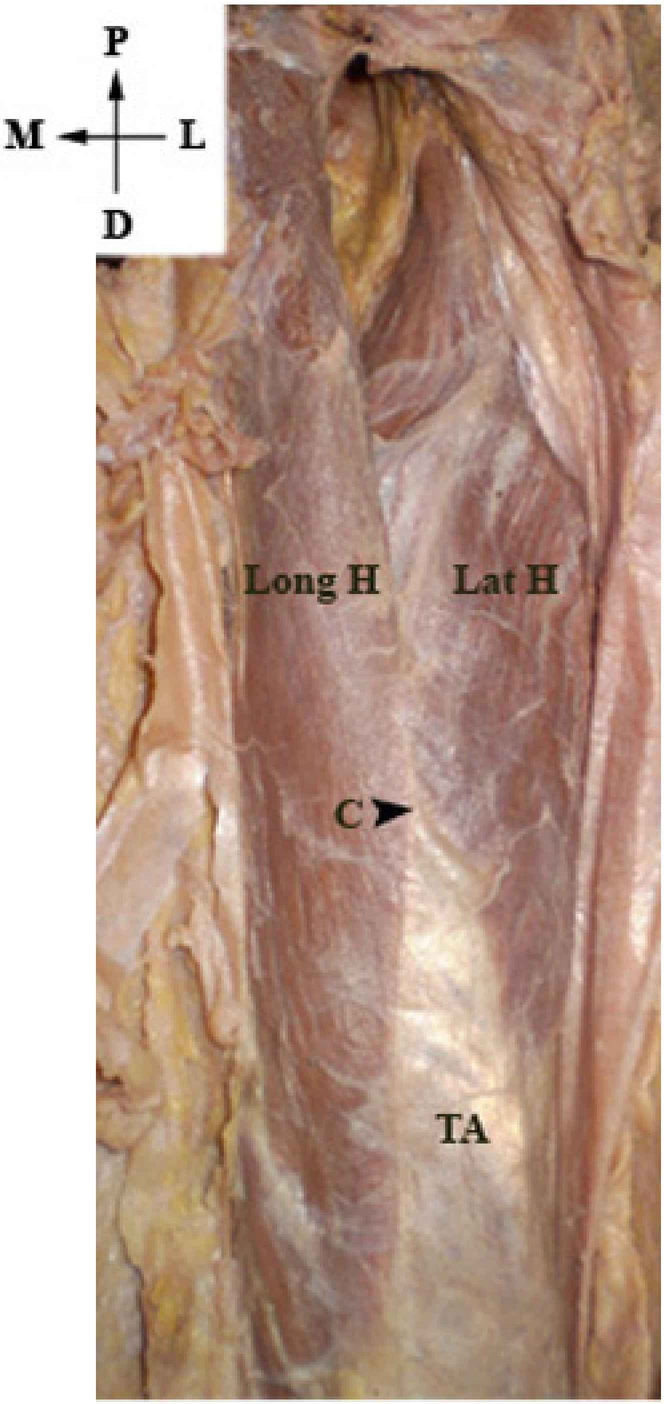


Fig. 6 . Posterior view of right arm showing the point of confluence of long head of triceps, lateral head of triceps and triceps aponeurosis C-point of confluence; Long H-long head; Lat H-lateral head; TA-triceps aponeurosis

The mean distance between radial nerve lying along the posterior aspect of humerus and confluence point was 39.7 ± 11.8mm. Mean distances for right arm and left arm were 39.3 ± 11.5 mm and 40.1± 12.6 mm, respectively (Table 3).

Table 4. Measurements of Radial Nerve and Aponeurosis of Triceps

Parameter	Mean distance (mm)	SD (mm)	Range (mm)
A: Shortest distance of radial nerve to lateral humeral epicondyle	20.4	6.2	10.2 - 32
B: Lateral humeral epicondyle to superior margin of spiral groove	188.4	13.6	158 - 208
C: Lateral humeral epicondyle to inferior margin of spiral groove	127.4	17.1	90 - 165
D: 1/4 Aponeurosis of triceps to nerve	19.5	5.5	10.4 - 29.6
E: 2/4 Aponeurosis of triceps to nerve	15.3	4.2	6.9 - 24.6
F: 3/4 Aponeurosis of triceps to nerve	13.3	4	5.5 – 23.4
G: 4/4 Aponeurosis of triceps to nerve	12	4	4.6 - 23
H: Length of spiral groove	62.4	15.7	13 – 82

6.4 Distance between lateral epicondyle and spiral groove

Distance between lateral humeral epicondyle and superior and inferior margins of spiral groove are shown in Table 4. The length of spiral groove was calculated from these measurements. The mean distance between lateral humeral epicondyle and superior margin of spiral groove was 188.4 ± 13.6 mm. The minimum distance was

158 mm and maximum was 208 mm. The mean distance between lateral humeral epicondyle and inferior margin of spiral groove was 127.4 ± 17.1mm. The minimum distance was 90 mm and maximum was 165 mm. The shortest distance between radial nerve and midpoint of lateral humeral epicondyle was found to be 20.4 ± 6.2 mm. The minimum distance was 10.2 mm and maximum was 32 mm.

The mean length of spiral groove was found to be 62.4 ± 15.7 mm. The minimum length of spiral groove was 13 mm and the maximum was 82 mm (Chart 2).

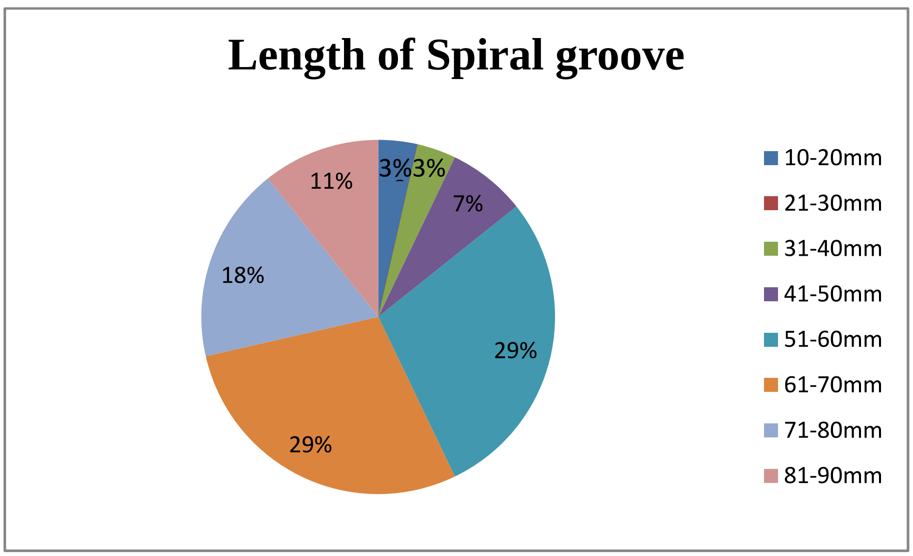


Chart 2. Length of Spiral groove

6.5 Distance between triceps aponeurosis and radial nerve

The triceps aponeurosis was marked in to four equal parts in a distal-proximal sequence and the distances between each part and the radial nerve was measured (Table 4).

Distance between one –fourth aponeurosis and radial nerve

The mean distance between one –fourth aponeurosis and radial nerve was 19.5 ± 5.5mm. The minimum distance was 10.4 mm and maximum was 29.6 mm.

Distance between two –fourth aponeurosis and radial nerve

The mean distance between two –fourth aponeurosis and radial nerve was 15.3 ± 4.2mm. The minimum distance was 6.9 mm and maximum was 24.6mm.

Distance between three –fourth aponeurosis and radial nerve

The mean distance between three –fourth aponeurosis and radial nerve was 13.3 ± 4mm. The minimum distance was 5.5 mm and maximum was 23.4 mm.

Distance between four –fourth aponeurosis and radial nerve

The mean distance between four –fourth aponeurosis and radial nerve was 12 ± 4 mm. The minimum distance was 4.6 mm and maximum was 23 mm.

6.6 Variables to trace the individual branches for long head, lateral head and medial head of triceps brachii

<u>Nerve branches for long head of triceps brachii</u>

Table 5. The Number and Location of Origin and Entry Point of Branches for Long Head of Triceps Brachii

	n = 28
Number of branches 1 2 3 4	 89.3% 10.7% 0% 0%
<u>Origin of branches</u> Location Proximal to spiral groove On the spiral groove Proximal and on spiral groove	 100% 0% 0%
<u>Distance of origin of branch</u> From inferior border of teres major From inferior end of deltoid	 9.9 ± 5.5mm (3.7 -26.8 mm) 62.8 ± 16.1mm (17.2 - 93 mm)
<u>Distance of entry point of branch</u> From inferior end of deltoid	 48.6 ± 15.4mm (13.9 – 79.1mm)

One branch from radial nerve innervated long head in 89.3% of arms (Table 5). Two branches were seen in 10.7% of arms. None of the arms were innervated by three (0%) or four branches (0%). The mean number of branches for long head was 1.1.

Origin of branches for long head in relation to spiral groove

Origin of branches for long head were found proximal to spiral groove in all arms (100%). There were no branches given off on spiral groove (0%) and also proximal and on spiral groove (0%).

Distance between origin of branch for long head of triceps and inferior end of deltoid

Distance of origin of branch to long head of triceps from inferior end of deltoid was 62.8 ± 16.1mm (Fig. 3). The minimum distance was17.2 mm and the maximum was 93 mm.

Distance between entry point of branch for long head and inferior end of deltoid

Distance of entry point of branch to long head from inferior end of deltoid was 48.6 ± 15.4 mm. The minimum distance was 13.9 mm and the maximum was 79.1mm.

Distance between origin of branch for long head and inferior border of teres major

Distance of origin of branch for long head of triceps from inferior border of teres major was 9.9 ± 5.5 mm. The minimum distance was 3.7 mm and the maximum was 26.8 mm.

<u>Nerve branches for lateral head of triceps brachii</u>

Table 6. The Number and Location of Origin and Entry Point of Branches for Lateral Head of Triceps Brachii

	n = 28
Number of branches	
1	89.3%
2	10.7%
3	0%
4	0%
<u>Origin of branches</u>	
Location	
Proximal to spiral groove	7.1%
On the spiral groove	92.9%
Proximal and on spiral groove	0%
<u>Distance of origin of branch</u>	
From the inferior border of teres major	10.0 ± 7.3mm (3.4 – 33.3 mm)
From inferior end of deltoid	56.1 ± 15.8mm (11.4 – 88.9 mm)
<u>Distance of entry point of branch</u>	
From inferior end of deltoid	26.7 ± 11.7mm (4 – 50.6 mm)

One branch from radial nerve innervated lateral head in 89.3% of arms (Table 6). Two branches were seen in 10.7% of the arms. None of the arms were innervated by three (0%) or four branches (0%). The mean number of branches for lateral head was 1.1.

Origin of branches for lateral head in relation to spiral groove

In 92.9%, the branches to lateral head arose on spiral groove. The origin of branches for lateral head were found proximal to spiral groove in 7.1% of specimens. There were no branches proximal and on spiral groove (0%).

Distance between origin of branch for lateral head of triceps and inferior end of deltoid

Distance of origin of branch to lateral head of triceps from inferior end of deltoid was 56.1 ± 15.8 mm (Fig. 3). The minimum distance was 11.4 mm and the maximum was 88.9 mm.

Distance between entry point for lateral head of triceps and inferior end of deltoid

Distance of entry point of branch for lateral head from inferior end of deltoid was 26.7 ± 11.7 mm. The minimum distance was 4 mm and the maximum was 50.6 mm.

Distance between origin of branch for lateral head and inferior border of teres major

Distance of origin of branch for lateral head of triceps from inferior border of teres major was 10.0 ± 7.3 mm. The minimum distance was 3.4 mm and the maximum was 33.3 mm.

<u>Nerve branches to medial head of triceps brachii</u>

Table 7. The Number and Location of Origin and Entry Point of Branches for Medial Head of Triceps Brachii

	n = 28
Number of branches	
1	92.9%
2	7.1%
3	0%
4	0%
<u>Origin of branches</u>	
Location	
Proximal to spiral groove	92.9%
On the spiral groove	7.1%
Proximal and on spiralgroove	0%
<u>Distance of origin of branch</u>	
From inferior border of teres major	16.7 ± 10.8mm (4.7 – 43.7 mm)
From inferior end of deltoid	49.3 ± 19.1mm (14.6 – 95.4 mm)
<u>Distance of entry point of branch</u>	
From inferior end of deltoid	27.8 ± 16 mm (6.8 – 62.6 mm)

One branch from radial nerve innervated medial head in 92.9% of arms (Table 7). Two branches were seen in 7.1% of arms. None of the arms were innervated by three (0%) or four branches (0%). The mean number of branches for medial head was 1.1.

Origin of branches for medial head in relation to spiral groove

Origin of branches for medial head were found proximal to the spiral groove in all arms (92.9%). There were 7.1% branches on the spiral groove and no branches proximal and on spiral groove (0%).

Distance between origin of branch for medial head of triceps and inferior end of deltoid

Distance of origin of branch for medial head of triceps from inferior end of deltoid was 49.3 ± 19.1 mm (Fig. 3). The minimum distance was 14.6 mm and the maximum was 95.4 mm.

Distance between entry point of branch for medial head of triceps and inferior end of deltoid

Distance of entry point of branch for medial head from inferior end of deltoid was 27.8 ± 16 mm. The minimum distance was 6.8 mm and the maximum was 62.6 mm.

Distance between origin of branch for medial head of triceps and inferior border of teres major

Distance of origin of branch for medial head of triceps from inferior border of teres major was 16.7 ± 10.8 mm. The minimum distance was 4.7 mm and the maximum was 43.7 mm.

Comparison between sides

Comparison of certain parameters between side of the specimen was done using paired t-test (Table 8). No significant difference between sides was found.

Table 8. Comparison of measurements between sides

Parameters	P value
Distance between tip of acromion and transepicondylar line	0.66
Distance between tip of acromion and point where radial nerve entered spiral groove	0.88
Distance between tip of acromion and point where radial nerve left spiral groove	0.99
Distance between tip of acromion and point where radial nerve pierced lateral intermuscular septum	0.30
Distance between transepicondylar line and site of termination of radial nerve	0.79

6.7 First branch of radial nerve to triceps brachii

Table 9. The Number and Location of First Branch from Radial Nerve to Triceps

First branch from Radial Nerve(Nerve to long head)	No. of arms	Percentage (%)	Mean distance from origin of first branch to inferior border of teres major (mm)
Location			
Proximal to inferior border of teres major	28	100	10.4 ± 6.6mm (3.7 – 29.4 mm)
At inferior border of teres major	0	0	0
Distal to inferior border of teres major	0	0	0

The first branch from radial nerve was nerve for long head (Table 9). Origin of first branch of radial nerve for long head of triceps brachii in relation to teres major muscle is shown in Fig. 7.

The branches for long head were given off proximal to spiral groove (100%). The mean distance between origin of branch and inferior border of teres major was 10.4 ± 6.6 mm. The minimum distance was 3.7 mm and the maximum was 29.4 mm.

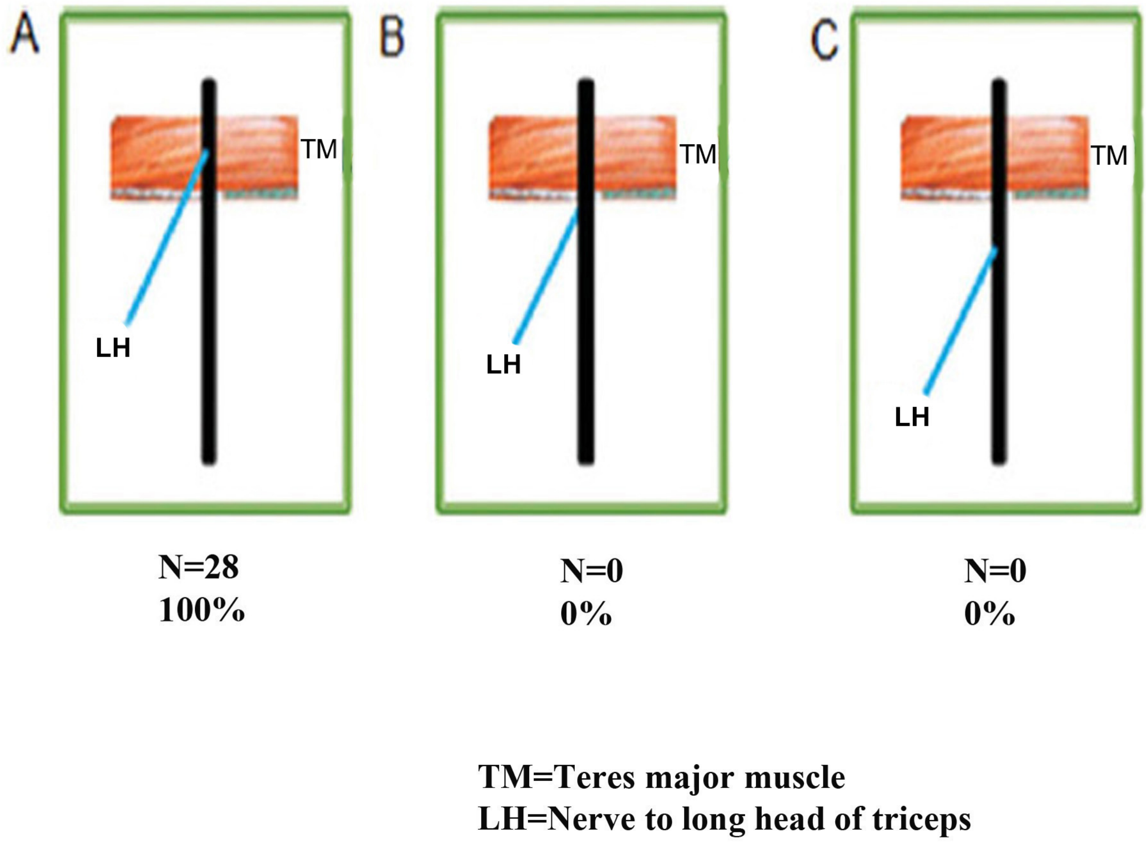


Fig. 7 . The diagram shows the branching of the nerve to the long head of the triceps with relation to the teres major muscle.
A: The nerves to the long head of the triceps from the radial nerve proximal to the inferior margin of the teres major muscle.
B:The nerve to the long head of the triceps from the radial nerve at the inferior margin of the teres major muscle.
C:The nerve to the long head of the triceps from the radial nerve distal to the inferior margin of the teres major muscle.

Line diagram ref: Surgical Anatomy of the Radial Nerve Branches to Triceps Muscle by Uerpairojkit et al. (2013)

6.8 <u>Innervation of medial head of triceps brachii</u>

Table 10. Innervation pattern of medial head of triceps brachii

Type of Innervation	No. of arms	Percentage (%)
Single Innervation	26	92.9
Double Innervation	2	7.1

Single innervation for medial head from radial nerve was found in 92.9% of arms (Table 10) (Fig. 8). Double innervation of medial head of triceps brachii was found in 7.1% of arms (Fig. 9).

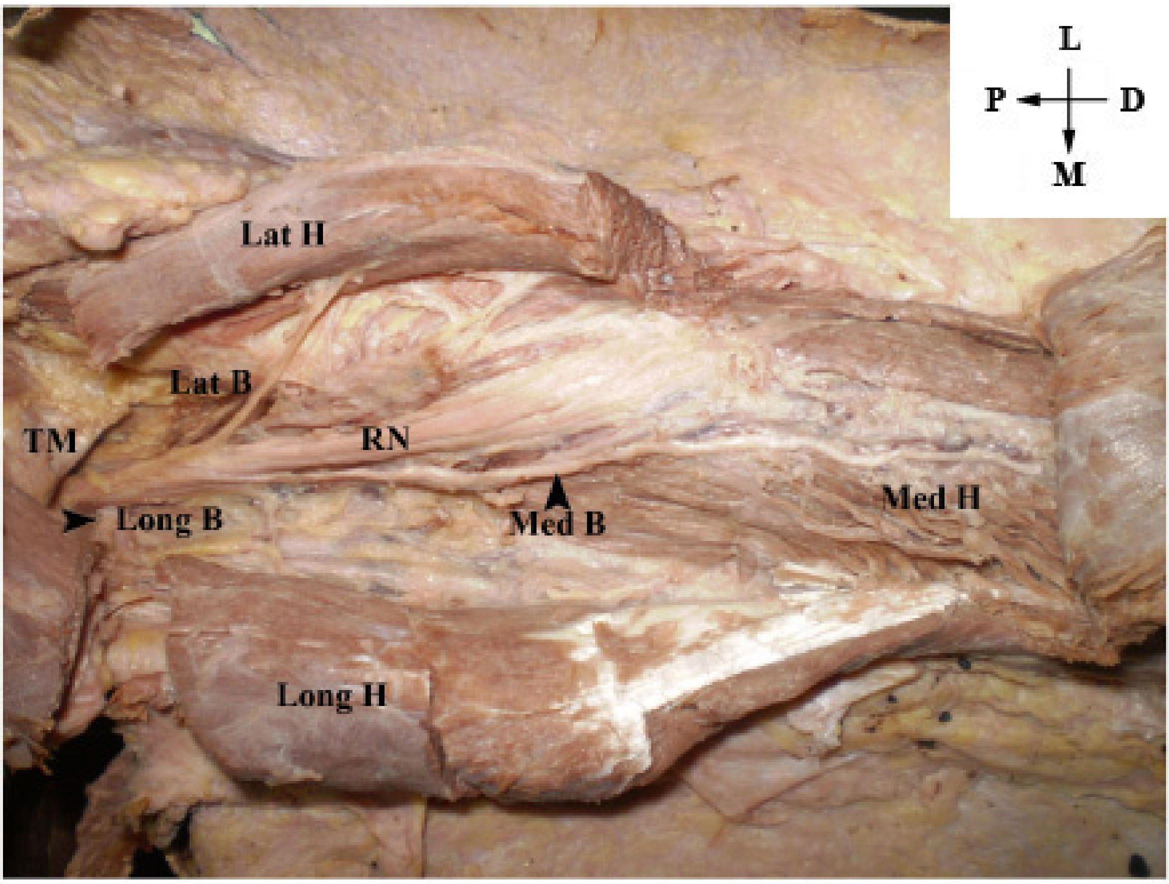


Fig. 8 . Posterior view of right arm showing single innervation of the medial head of triceps brachii.
RN-radial nerve; Long H-long head; Lat H-lateral head; Med H-medial head; Long B- branch to long head; Lat B-branch to lateral head; Med B-branch to medial head; TM- teres major

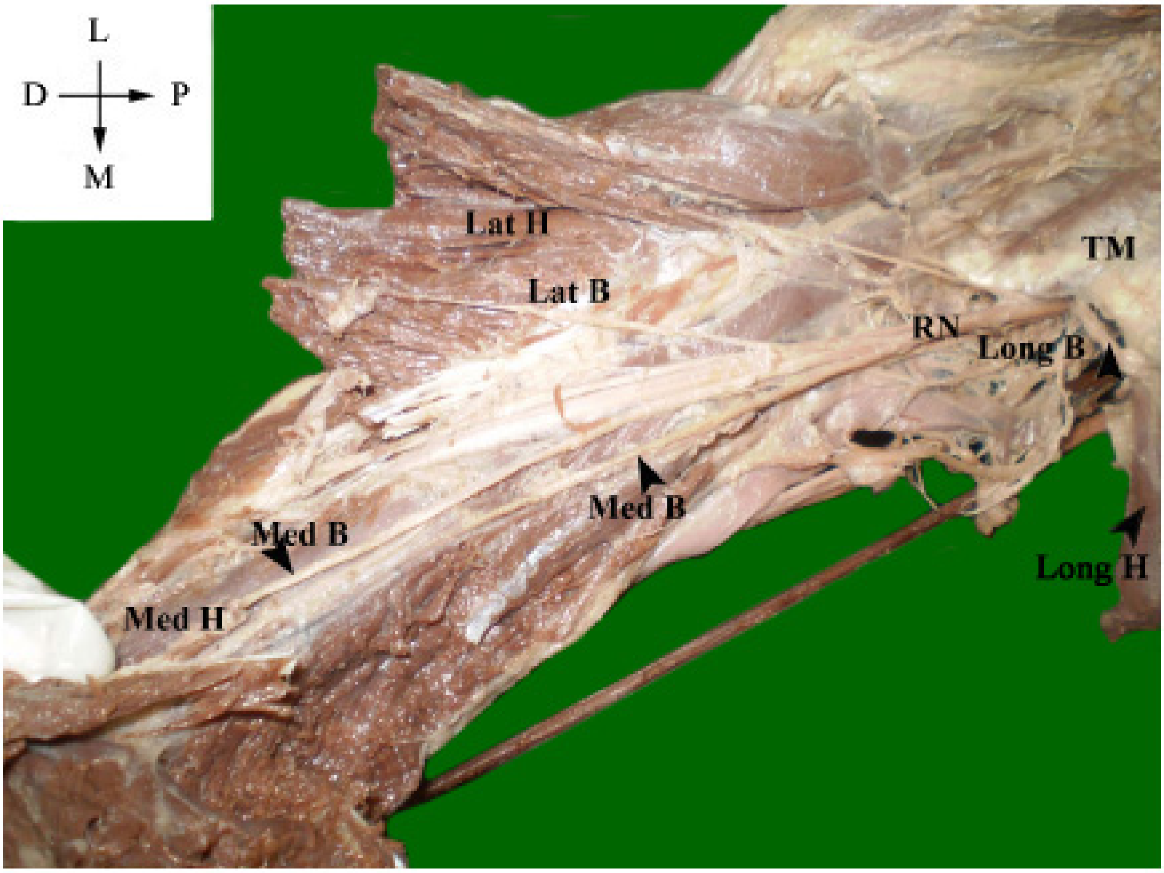


Fig. 9 . Posterior view of left arm showing double innervation of the medial head of triceps brachii.
RN- radial nerve; Long H-long head; Med H-medial head; Lat H- lateral head; Long B- branch to long head; Med B- branch to medial head; Lat B-branch to lateral head; TM-teres major

6.9 Pattern of branching of nerves to triceps brachii

The number of branches to triceps brachii as a whole are shown in Table 11.

Table 11. The Number of Nerve Branches to Triceps Brachii

No. of Nerve Branches	No. of arms	Percentage (%)
5	1	3.6
4	3	10.7
3	22	78.6
2	2	7.1

The pattern of branching of nerves to triceps brachii was classified as A, B, C, and D as done in the study by Uerpairojkit et al. (58). A diagrammatic representation of different patterns as seen in the study by Uerpairojkit et al. (58) are shown in Fig. 10. The patterns observed in the present study are shown in Table 12 and Chart 3. .

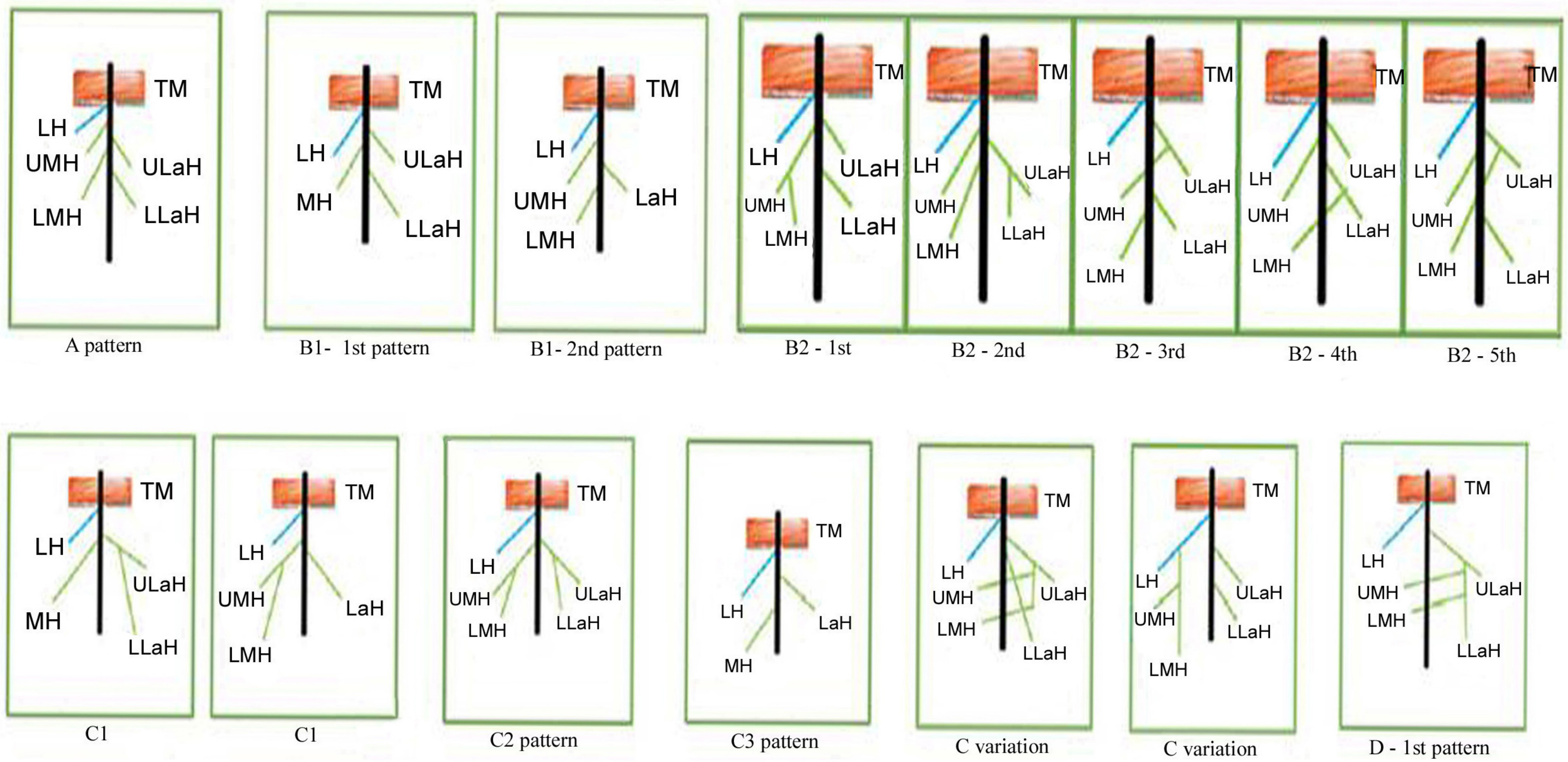


Fig.10 . Classification of the pattern of the nerve to the triceps.

A:There were five branches to the triceps.

B1:There were four branches, but there were two types

C,B2:There were four branches, but there was one common branch either on the lateral head or the medial head

D,C1:There were three branches with one common branch.

E,C2:There were two common branches on both the medial and lateral heads.

F,C3:There were three branches without common branches.

G,C variations type: The branches to the medial head are from the upper branch to the lateral head.

H,D:There were only two branches from the radial nerve with one common trunk from the upper lateral head branch.

Ref:Surgical Anatomy of the Radial Nerve Branches to Triceps Muscle by Uerpairojkit et al. (2013)

Table 12. The Different Patterns of Nerve Branches to Triceps Brachii

Types of Patterns		No. of arms	Percentage (%)
A	5 branches	1	3.6
B1	4 branches	1	3.6
B2	4 branches (onebranch which is common)	1	3.6
B2 (6^{th} Pattern)	4 branches (two branches to lateral head)	1	3.6
C1	3 branches(one branch which is common)	0	0
C2	3 branches(two common branches)	0	0
C3	3 branches without common branches	22	78.6
C variations	Three branches (variation)	0	0
Type D	Two branches	0	0
Type D (2^{nd} Pattern)	Two common branches	2	7.1

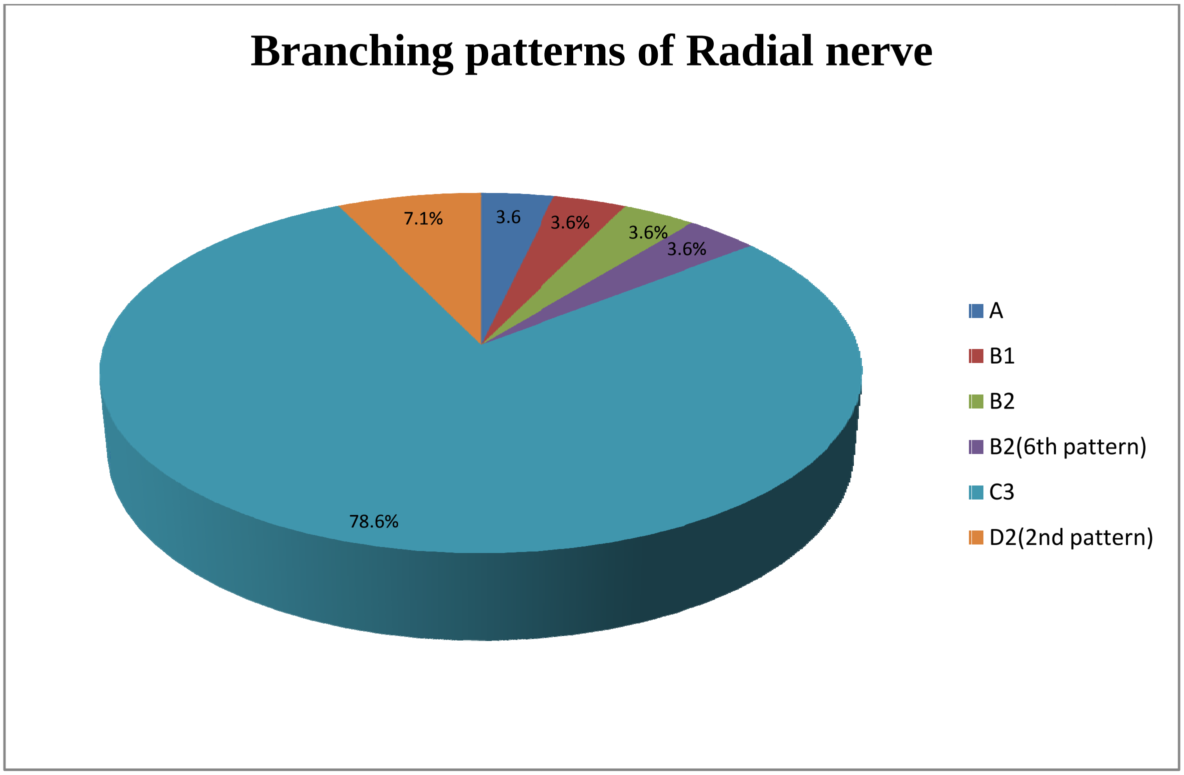


Chart 3. Different branching patterns of Radial nerve to Triceps brachii

Type A pattern

There were five branches in this pattern. The branches were to the long head, upper part of lateral head, lower part of lateral head, upper part of medial head and lower part of medial head. It was seen in 3.6% of arms (Fig. 11).

Type B1 – 1st pattern

This is a subtype of B pattern. There were four branches. The B1-1st pattern was seen in 3.6% of arms. The four branches were - two branches separately innervating lateral head (branch for upper part of lateral head and branch for lower part of lateral head), a branch for long head and a branch for medial head of triceps brachii (Fig. 12).

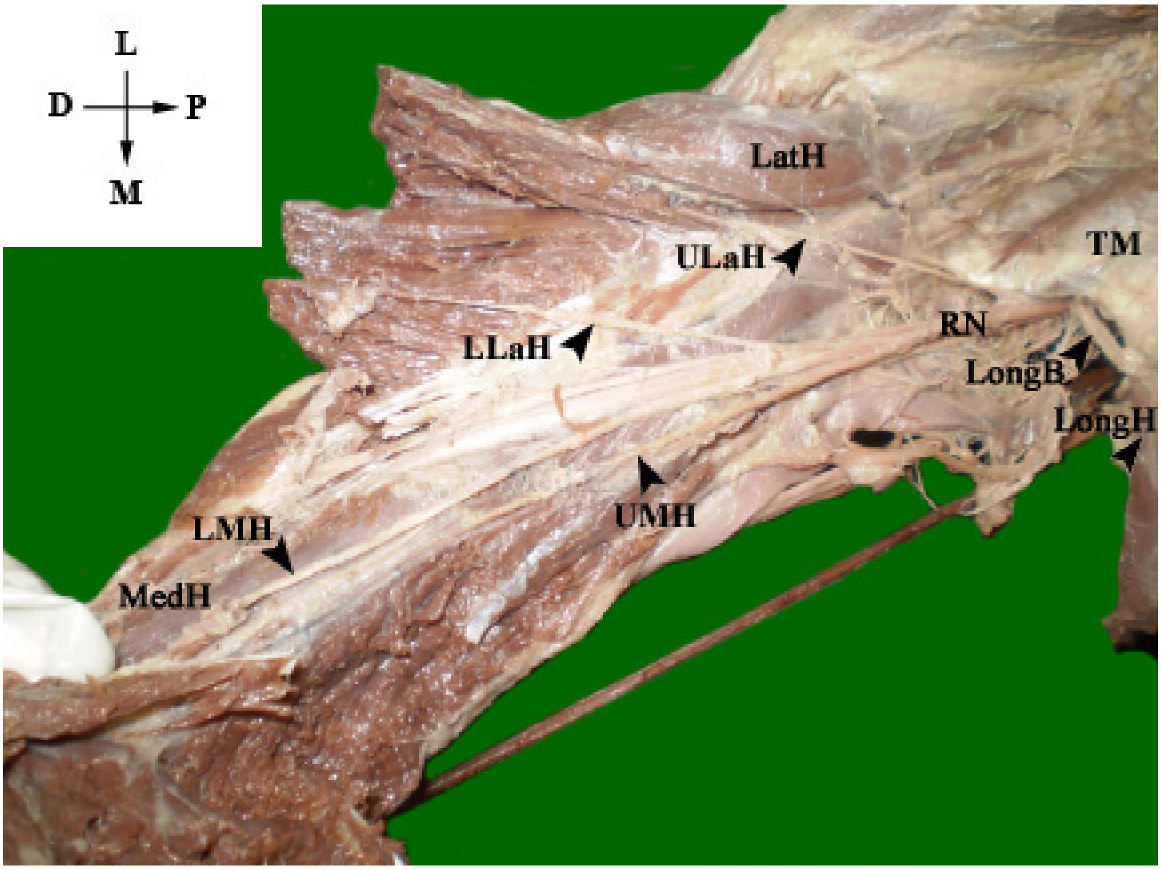


Fig.11. Posterior view of left arm showing type A pattern of radial nerve branches to triceps brachii.
RN-radial nerve; Long H-long head; LatH-lateral head; MedH-medial head; Long B-branch to long head; ULaH-branch to upper lateral head; LLaH-branch to lower lateral head; UMH-branch to upper medial head; LMH-branch to lower medial head; TM-teres major

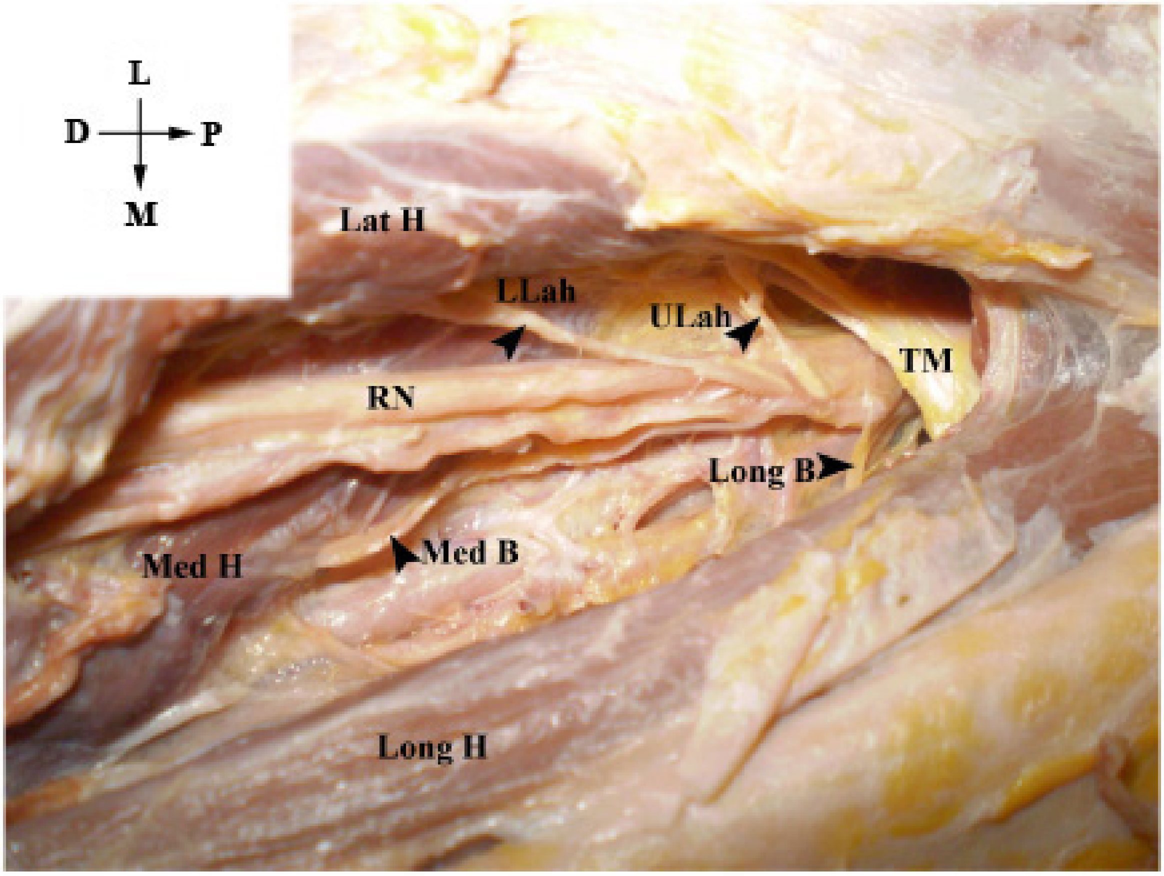


Fig.12 . Posterior view of left arm showing type B1- 1st pattern of radial nerve branches to triceps brachii.
RN-radial nerve; Long H-long head; Lat H-lateral head;
MedH-medial head; LongB - branch to long head;
ULah-branch to upper lateral head; LLah-branch to lower lateral head;
MedB - branch to medial head; TM-teres major

Type B2 – 2nd pattern

This is a subtype of B pattern. There were 4 branches with one branch which was common. B2 - 2nd pattern was seen in 3.6% of arms. The four branches were – a common branch dividing into two which innervated upper part of lateral head and lower part of lateral head, a branch for long head and branches to upper part of medial head and lower part of medial head of triceps brachii (Fig. 13).

Type B2 – 6th pattern

This was a new pattern seen only in the present study. It comes under type B2, since there were 4 branches with one branch which was common. B2 - 6th pattern is seen in 3.6%.of arms. There was a branch for lateral head and another common branch which divided into two innervating upper part of lateral head and lower part of lateral head. There was one branch for long head and one for medial head of triceps brachii (Fig. 14).

Type C3 pattern

The type C3 pattern is the most common type of nerve branching pattern found in this study (78.6%). This pattern has 3 branches – one branch to each head of the triceps brachii (Fig. 15).

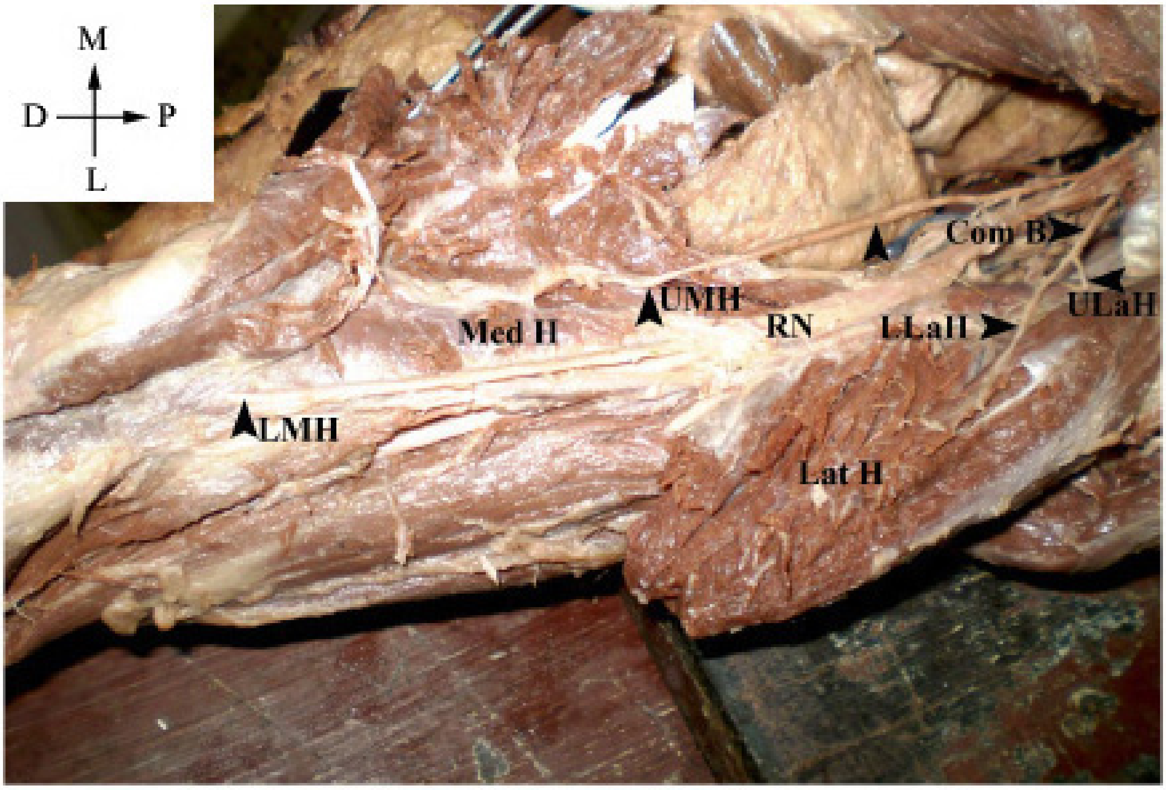


Fig.13 . Posterior view of right arm showing type B2 - 2nd pattern of radial nerve branches to triceps brachii.
RN-radial nerve; Lat H-lateral head; Med H-medial head;
Com B-common branch; ULaH-branch to upper lateral head;
LLaH-branch to lower lateral head; UMH-branch to upper medial head;
LMH- branch to lower medial head; The long head of triceps had one branch, which is not seen in this view of the picture

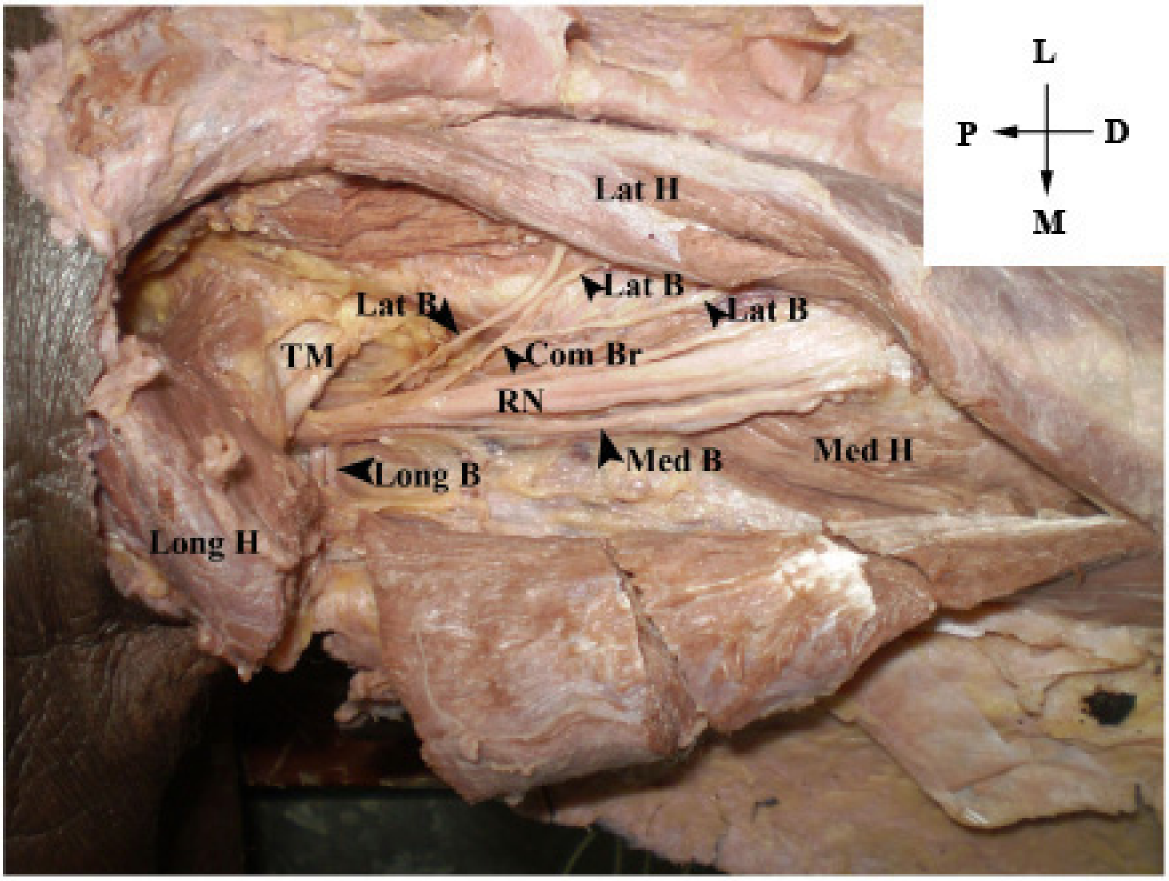


Fig.14 . Posterior view of right arm showing type B2 - 6th pattern of radial nerve branches to triceps brachii.
RN-radial nerve; Long H-long head; Lat H-lateral head; Med H-medial head; Com Br-common branch; Lat B-branch to lateral head; Long B-branch to long head; Med B-branch to medial head; TM-teres major

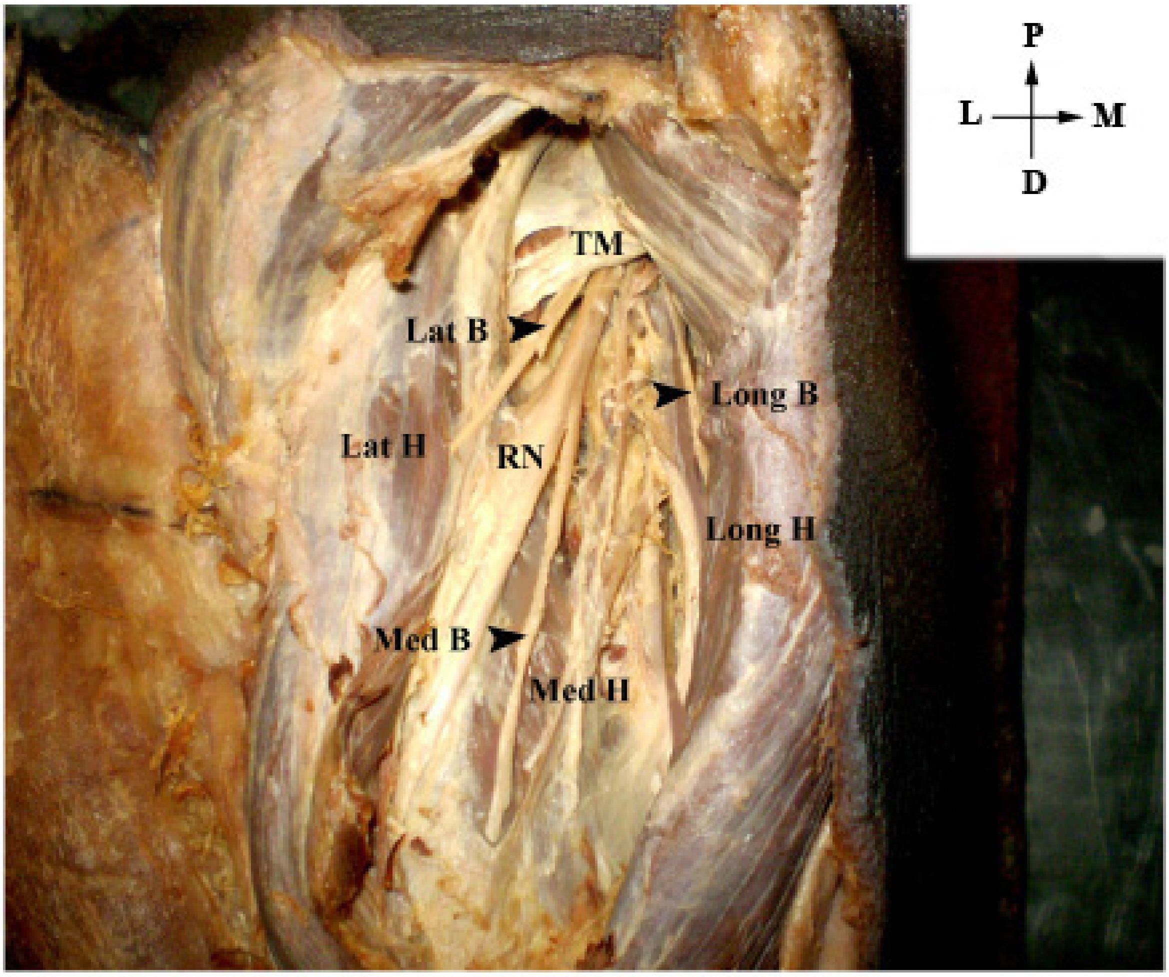


Fig.15. Posterior view of left arm showing type C3 pattern of radial nerve branches to triceps brachii.
RN-radial nerve;Long H-long head; Lat H-lateral head;
MedH-medial head;LongB - branch to long head;
Lat B-branch to lateral head;MedB - branch to medial head;
TM-teres major

Fig .16. Posterior view of left arm showing D - 2nd pattern of radial nerve branches to triceps brachii. There are two common branches in this arm.
RN- radial nerve; Long H - long head; Lat H - lateral head; Med H- medial head;
ComBr - common branch; ULaH - branch to upper lateral head;
UMH - branch to upper medial head; TM - teres major
In A, the common branch divides to supply ULaH and UMH.
In B, the common branch divides to supply the Long H.

Type D – 2nd pattern

This type D – 2nd pattern was a new pattern seen only in the present study (7.1%). There were two common branches. One common branch divided into two branches which innervated the upper lateral head and upper medial head. The other common branch divided into two branches and innervated the long head (Fig. 16).

Other patterns

Types C1, C2, C variations and type D-1st patterns were not seen in the present study.

7. Discussion

Knowledge of anatomy of radial nerve is important in treatment procedures of humeral fractures. Fracture shaft of humerus accounts for approximately 3% to 5% of all fractures (62). The radial nerve is the most commonly injured peripheral nerve in humeral shaft fractures (31). The incidence of radial nerve injury has been found out to be between 2% and 17% (average 11%) (35, 40, 41).

Humeral shaft fractures

Radial nerve injury depends upon fracture site, whether it is in the distal third or the mid-third of the shaft of humerus. The Holstein-Lewis type of fracture accounted for 7.5% and it resulted in acute radial nerve palsy of 22% (65). In a systematic review, it has been found that middle and distal shaft fractures of humerus had an higher injury rate of the radial nerve (2). The fracture pattern also determines the radial nerve injury (2,66). Transverse and oblique fractures have an association with radial nerve palsy (2). The treatment procedure of humeral fractures can be either conservative or surgical. The routine treatment of angulated humeral fractures is found to be simple and cost effective with less neurovascular complications (67). Studies have revealed that the treatment procedure for closed humeral shaft fractures is along a conservative line. The open humeral shaft fractures need to be treated surgically with early exploration of the radial nerve. The surgical treatment for fractures of shaft of humerus include open reduction with intramedullary nailing and plating with screws.

Palsy of radial nerve can be either primary occurring at the time of injury (63,64) or secondary developing during the course of treatment (68). Intraoperative causes for radial nerve palsy have been reported in several studies (11–15). A proximal lesion of radial nerve can lead to wrist drop and loss of sensation on the dorsal surface of the hand. Usage of palpable landmarks to locate the radial nerve intraoperatively during humeral exposures can help the surgeon to minimize iatrogenic injury

Bony landmarks used to trace Radial Nerve course

The externally palpable bony landmarks like the tip of acromion and epicondyles (medial and lateral) will be very useful for the Orthopedician to assess the site of radial nerve prior to surgery in the treatment of humeral fractures.

Distance between tip of acromion and transepicondylar line

Cho et al. (4) in their study, in the Korean population, have found the mean distance between tip of acromion and transepicondylar line to be 289.5 mm. Males had a longer distance (302.0 mm) than females (278.1 mm).

In the present study, the mean distance between tip of acromion and transepicondylar line was found to be 268.1 ± 28 mm. In males, the distance was longer (276± 27mm) than in females (244± 18mm), as in the study by Cho et al. (4). Difference in length can be attributed to racial differences.

Radial nerve and spiral groove

Cho et al. (4) in their study found the mean distance between tip of acromion and the site where radial nerve entered spiral groove was 46.7% ± 3.1% of the mean distance between tip of acromion and transepicondylar line.

In the present study, the mean distance between tip of acromion and the site where radial nerve entered spiral groove was found to be 109.4 ± 24.4 mm. This distance was found to be 40.6% ± 6.2% of the mean distance between tip of acromion and transepicondylar line.

In the study by Cho et al. (4), the mean distance between tip of acromion and the site where radial nerve left spiral groove was 60.5% ± 5.4% of the mean distance between tip of acromion and transepicondylar line.

In the present study, the mean distance between tip of acromion and site where radial nerve left spiral groove was 146.8 ± 25.7mm. This distance was found to be 54.7% ± 6.7% of the mean distance between tip of acromion and transepicondylar line.

The site of spiral groove is important during the treatment of fractures of the midshaft of humerus. The acromion process is an easily palpable bony landmark and the knowledge of the distance of the spiral groove from the acromian process will be helpful to the Orthopedician during intervention procedures.

There are studies where measurements to the spiral groove were made from the lateral epicondyle. Carlan et al. (49), found the distance from lateral humeral epicondyle to proximal and distal margins of spiral groove to be 171 ± 1.6 mm and 109 ± 1.5 mm respectively and the length of the spiral groove was 62 mm. Chaudhry et al. (5), in their study found the distance from lateral epicondyle to proximal and distal margins of spiral groove to be 156 ± 1.3 mm and 111± 1.2 mm respectively and length of spiral groove was found to be 48 ± 0.6 mm.

In the present study, the distance from lateral epicondyle to proximal and distal margins of spiral groove was found to be 188.4 ± 13.6 mm and 127.4± 17.1 mm respectively and the length of spiral groove was found to be 62.4± 15.7 mm. The present findings were similar to that of Carlan et al. (49) (Table 13) (Chart4).

Table 13. Studies showing comparable values of spiral groove

	Carlan et al. (2007)	Chaudhry et al. (2010)	Present study
	American Population	British Population	Indian Population
Distance from lateral epicondyle to proximal margin of spiral groove	171 ± 1.6 mm	156 ± 1.3 mm	188.4 ± 13.6 mm
Distance from lateral epicondyle to distal margin of spiral groove	109 ± 1.5 mm	111± 1.2 mm	127.4± 17.1 mm
Length of spiral groove	62 mm	48 ± 0.6 mm	62.4 ± 15.7 mm

In cases where the tip of acromion process is not palpable due to thick muscle mass or fracture dislocation, distances of spiral groove from lateral epicondyle can be used during intervention procedures. The spiral groove is one area where radial nerve lies directly on periosteum of humerus, mostly without intervening muscle fibres. The length of spiral groove is important because that is the area where the nerve is intimately related to humerus, rendering it more prone for injury in mid-shaft fractures and during usage of anterior approach for bicortical humeral fixation .

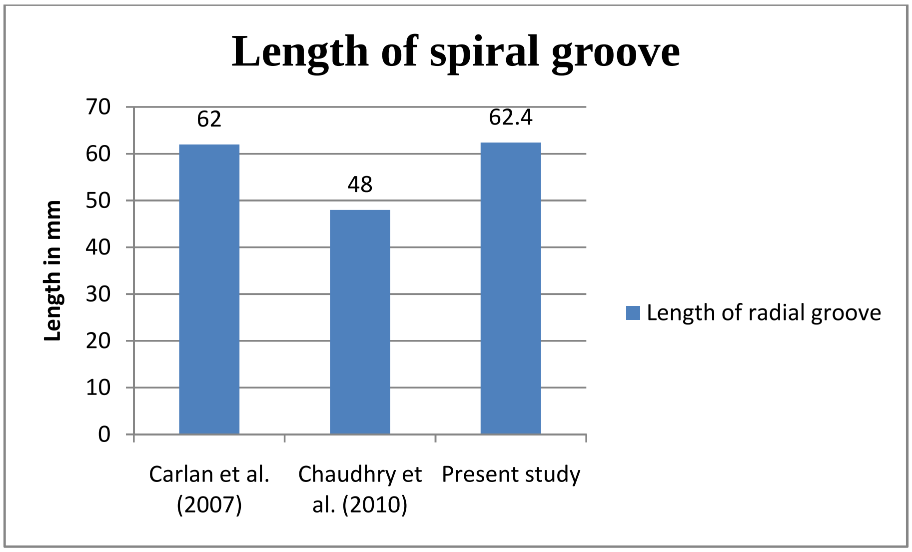


Chart 4. Length of spiral groove

Radial nerve and lateral intermuscular septum

In the study by Cho et al. (4), the mean distance between tip of acromion and site where radial nerve pierced lateral intermuscular septum was 66.8 % of the mean distance between tip of acromion and transepicondylar line.

In the present study, the mean distance between tip of acromion and the site where radial nerve pierced lateral intermuscular septum was 180.2 mm ± 30.3 mm. which was 67% ± 5.9% of the mean distance between tip of acromion and transepicondylar line. This is in accordance with the findings of Cho et al. (4)

Fleming et al. (21), found that radial nerve entered anterior compartment of arm at a point within 5 mm of the junction of distal third and middle third of an imaginary line joining the lateral most point of acromion process of scapula to lateral humeral epicondyle. Cox et al. (16), found the radial nerve pierced lateral intermuscular septum at a mean of 11.8 cm (range, 8.1–19.0 cm) proximal to lateral humeral epicondyle. This measurement represents 38% of humeral length. Hasan et al. (47),found that distance from the center of lateral humeral epicondyle to the site where radial nerve pierced lateral intermuscular septum was 11.2 ± 2.1 cm (range, 9.4–13.5). This finding is similar to that of Cox et al. (16).

The site where radial nerve pierced lateral intermuscular septum is important during intervention procedures in fracture distal half of humerus. There is chance of tethering of radial nerve at the site where it pierces lateral intermuscular septum (22). It was found that there was even immobilisation of nerve caused by the obliquely oriented septum. The acromion process is an easily palpable bony landmark and distance of the site where radial nerve pierced lateral intermuscular septum and acromion process can be easily determined and will be useful. In cases where the acromion process is not palpable due to thick muscle mass or fracture dislocation, distances between the site where radial nerve pierced lateral intermuscular septum and lateral epicondyle can be used during intervention procedures.

Radial nerve and its termination

The site of termination of radial nerve was studied. Cho et al. (4), found that the site of termination of radial nerve was at a mean distance of 5.7 ± 14.3 mm proximal to transepicondylar line. The division of radial nerve was above transepicondylar line in 65% of elbows, at the line in 2.5%, and below the line in 32.5% of elbows.

In the present study, the site of termination of radial nerve was 24.7 ± 8.8 mm proximal to transepicondylar line on an average. The division was above transepicondylar line in 85.7% of arms, at the line in 0%, and below the line in 14.3% (Chart 5).

Knowing the site of termination of radial nerve is important while treating lower end humeral fractures.

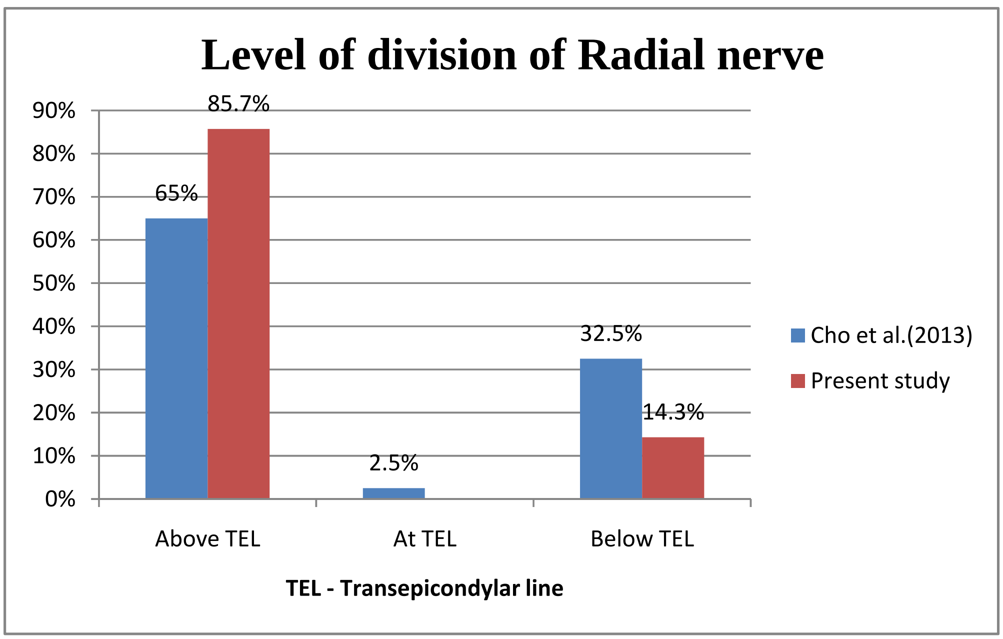


Chart 5. Level of division of Radial nerve

<u>Radial nerve at posterior midline of humerus</u>

Carlan et al. (49), found that the mean distance from distal part of deltoid tuberosity to radial nerve at posterior midline of humerus was 10 ± 0.2mm.

In the present study, the mean distance from distal part of deltoid tuberosity to radial nerve at posterior midline of humerus was 37.6 ± 13 mm.

The close relationship between posterior humerus and radial nerve renders it more prone for injury with mid-shaft fractures andduring usage of anterior approach for bicortical humeral fixation. When operative fixation is done using an anterior approach, deltoid tuberosity will be useful to locate radial nerve, as it is a consistent anatomic landmark.

Point of Confluence and radial nerve

Seigerman et al. (48), found the distance between point of confluence and radial nerve to be 39 ± 2.1mm in American population. Mean distances of right and left arms were 38.9 ± 1.86 mm and 39.1 ± 2.4 mm respectively.

In the present study, the distance between point of confluence and radial nerve was found to be 39.7 mm ± 11.8 mm. Mean distances of right and left arms were 39.3± 11.5 mm and 40.1± 12.6 mm respectively (Chart 6). This isin accordance with the findings of Seigerman et al. (48)

The anatomic intersection of long head of triceps, lateral head of triceps and aponeurosis of triceps(point of confluence) is useful as a superficial anatomic landmark for identification of radial nerve during posterior approach of humerus.

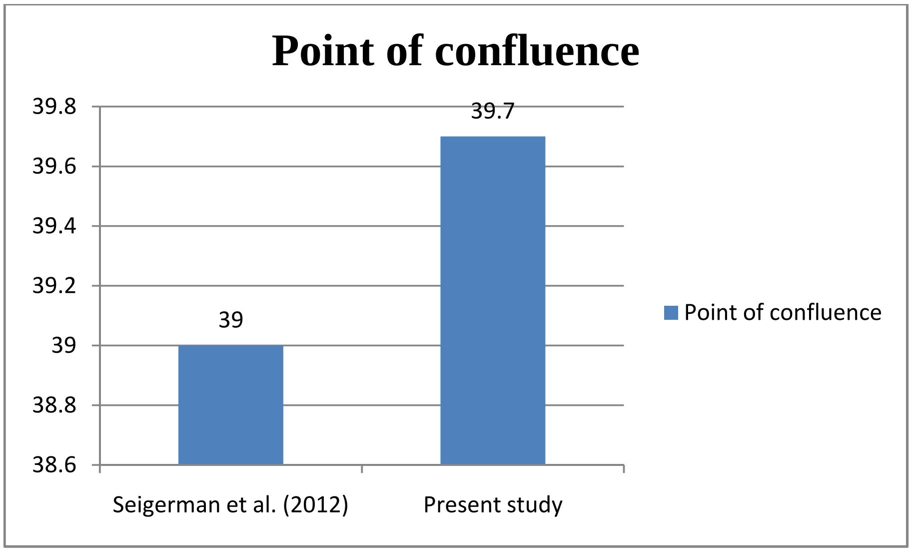


Chart 6. Point of Confluence

Radial nerve and aponeurosis of triceps

The radial nerve has a consistent course close to lateral border of aponeurosis of triceps.The distance between radial nerve and lateral border of aponeurosis of triceps was measured by marking triceps aponeurosis in to four equally spaced parts (1/4, 2/4, 3/4 and 4/4) in a distal-proximal sequence. The distances measured by Chaudhry et al. (5), from radial nerve to 1/4, 2/4, 3/4 and 4/4 of aponeurosis were 27 ± 0.5 mm, 23 ± 0.5 mm, 22 ± 0.7 mm and 26 ± 1.2 mm respectively.

In the present study, the distances from radial nerve to1/4, 2/4, 3/4 and 4/4 of aponeurosis were 19.5 ± 5.5 mm, 15.3 ± 4.2 mm, 13.3 ± 4 mm and 12 ± 4 mm respectively.

Chaudhry et al. (5) in their study, found radial nerve passed at a distance of 22–27 mm from lateral border of aponeurosis of triceps. The closest distance from the aponeurosis was 13± 1mm.

In the present study, radial nerve passed close to lateral border of aponeurosis of triceps at a distance of 12–19.5 mm. The closest distance between aponeurosis and radial nerve was 4.6 mm. The lateral border of aponeurosis of triceps is easy to identify and the present findings may help identify radial nerve during exploration. The present study revealed that radial nerve is closer to lateral border of aponeurosis of triceps in the Indian population than in the British population as shown in the study by Chaudhry et al. (5). This would suggest that immediate area (<4 mm) parallel to aponeurosis represents a ‘‘safe’’ region that can be used to avoid intraoperative radial nerve injury.

<u>Radial nerve and its branches to each head of triceps</u>

Cho et al. (4), in their study found radial nerve gave a number of muscular branches for each head of triceps brachii. The maximal number of branches for long and medial heads of triceps was three and four for lateral head of triceps. The mean numbers of branches to long head, medial head, and lateral head were 1.2, 1.3, and 1.7, respectively.

In the present study, the maximal number of branches was two for each head of triceps. The mean numbers of branches to each head was 1.1 (Charts 7 – 9).

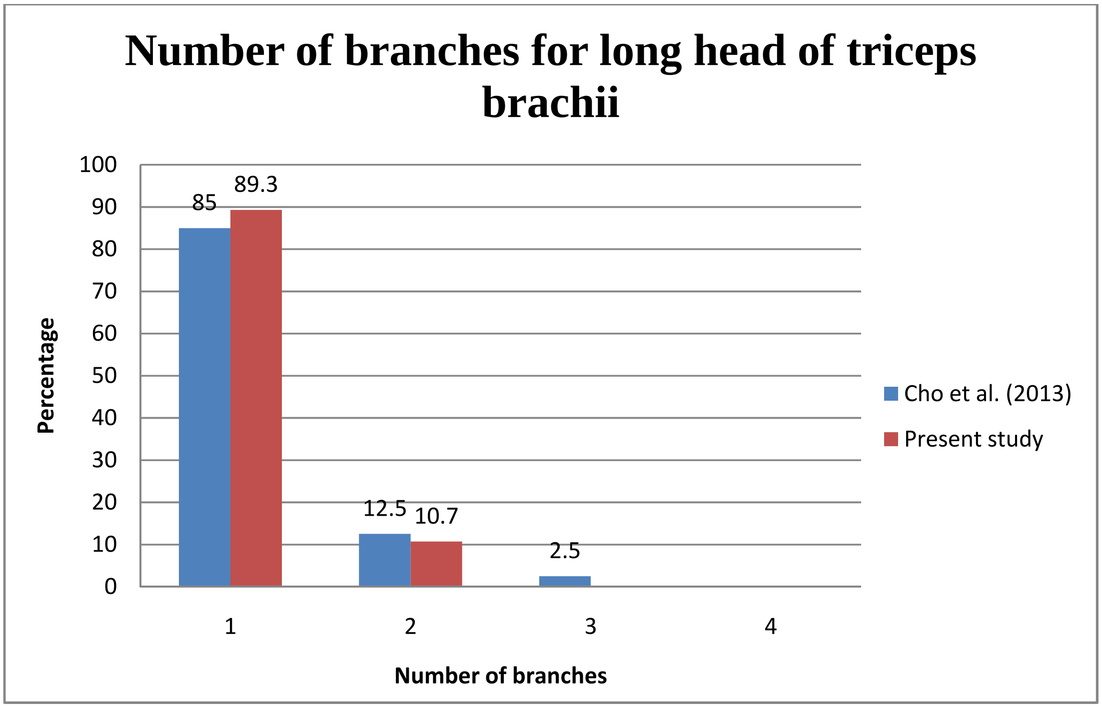


Chart 7. Number of branches for long head of triceps brachii

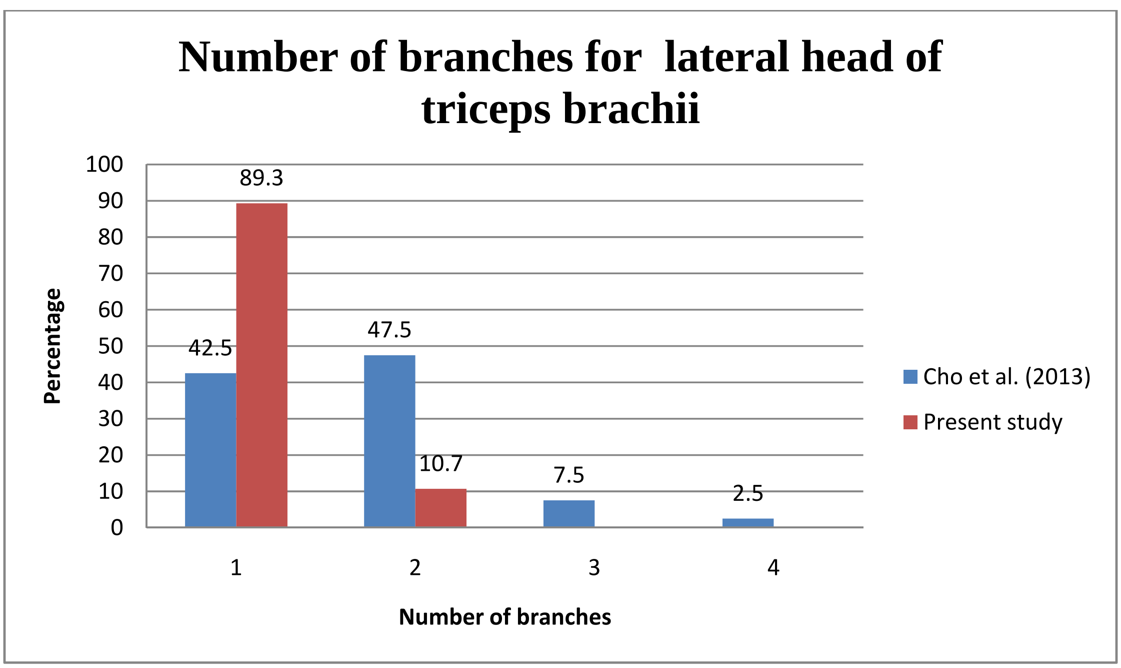


Chart 8. Number of branches for lateral head of triceps brachii

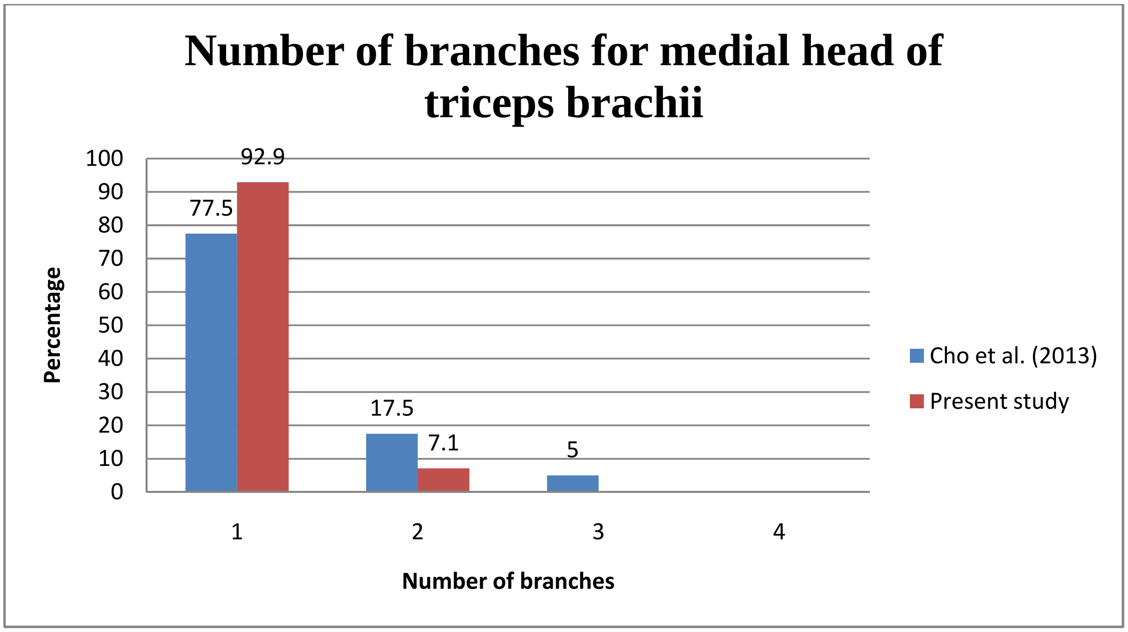


Chart 9. Number of branches for medial head of triceps brachii

<u>Radial nerve branches for long head of triceps</u>

In the study by Cho et al. (4), branches for long head of triceps were proximal to spiral groove in all specimens. The origin was at a mean distance of 24.4 mm proximal to inferior border of teres major. The level of origin of and entry point of branch for long head were 71.4 mm and 34.0 mm proximal to level of inferior end of deltoid respectively.

In the present study, the origin of branches for long head of triceps were proximal to spiral groove in all specimens. The origin was 9.9 ± 5.5 mm proximal to inferior border of teres major. The level of origin and entry point of branch for long head were 62.8± 16.1mm and 48.6 ± 15.4 mm proximal to level of inferior end of deltoid respectively (Table 14).

Radial nerve branches for lateral head of triceps

In the study by Cho et al. (4), branches for lateral head was given off proximal to spiral groove in 50% of arms, on spiral groove in 20% and proximal and on spiral groove in 30%. The origin of branch was 0.6 mm distal to inferior border of teres major. The level of origin and entry point of branch for lateral head were 50.7 mm and 19.3 mm proximal to inferior end of deltoid respectively.

In the present study, the origin of branches for lateral head were proximal to spiral groove in 7.1% of arms and on spiral groove in 92.9% of arms. The origin was on average 10 ± 7.3 mm proximal to inferior border of teres major. The level of origin and entry point of branch for lateral head were 56.1 ± 15.8 mm and 26.7± 11.7 mm proximal to inferior end of deltoid respectively (Table 14).

Radial nerve branches for medial head of triceps

In the study by Cho et al. (4), branches for medial head were given off proximal to spiral groove in 85% of arms, on spiral groove in 5% and proximal and on spiral groove in 10%. The origin of branch was 6 mm distal to inferior border of teres major. The level of origin and entry point of branch for medial head were 56.0 mm proximal and 16.4 mm distal to inferior end of deltoid muscle respectively.

In the present study, the origin of branches for medial head were proximal to spiral groove in 92.9% of arms and on spiral groove in 7.1% of arms. The origin was 16.7 ± 10.8 mm proximal to inferior border of teres major. The level of origin and entry point were 49.3 ± 19.1 mm and 27.8 ± 16 mm proximal to the inferior end of deltoid respectively (Table 14)

Table 14. Studies showing comparable values of the branches for triceps brachii

	Cho et al. (2013)			Present study		
	Korean Population			Indian Population		
	To long head (n = 40)	To lateral head (n = 40)	To medial head (n = 40)	To long head (n = 28)	To lateral head (n = 28)	To medial head (n = 28)
Number of branches						
1	85.0%	42.5%	77.5%	89.3%	89.3%	92.9%
2	12.5%	47.5%	17.5%	10.7%	10.7%	7.1%
3	2.5%	7.5%	5.0%	0.0%	0.0%	0.0%
4	0.0%	2.5%	0.0%	0.0%	0.0%	0.0%
<u>Origin of branches Location</u>						
Proximal to spiral groove	100%	50.0%	85%	100%	10.7%	92.9%
On the spiral groove	0.0%	20.0%	5.0%	0.0%	92.9%	7.1%
Proximal and on spiral groove	0.0%	30.0%	10.0%	0.0%	0.0%	0.0%
<u>Distance</u> From the inferior border of teres major	24.4±12.2 mm	-0.6±24.0 mm	6.0±21.9 mm	9.9 ± 5.5mm	10.0 ± 7.3mm	16.7 ± 10.8mm

The branches of triceps brachii can be transferred to axillary nerve for restoring function of deltoid. Knowledge of the distance of origin of branches of radial nerve for each head of triceps from inferior end of deltoid and teres major muscle is important when considering nerve transfer.

First branch of radial nerve

Uerpairojkit et al. (58) in their study on 79 arms found that the first branch from the radial nerve was the nerve to long head. A similar finding was seen in the present study. The study by Uerpairojkit et al. (58) showed the origin of nerve for the long head was proximal to inferior border of teres major in 48 arms (60.8%) (mean distance from inferior border of teres major was 13.5 mm with a range of 5–34 mm). In 17 arms (21.5%), branch for long head arose at inferior border of teres major and in 14 arms (17.7%), branch for long head arose distal to inferior border of teres major (mean distance from inferior border of teres major was 7.9 mm with a range of 2–23 mm).

In the present study, the nerve for long head had its origin from radial nerve proximal to inferior border of teres major in all 28 arms (mean distance from inferior border of teres major was 10.4 ± 6.6 mm with a range of 3.7–29.4 mm). In none of the arms, the nerve for long head took origin from radial nerve at the inferior border or distal to inferior border of teres major. The location of the first branch of radial nerve in relation to teres major is shown in Chart 10.

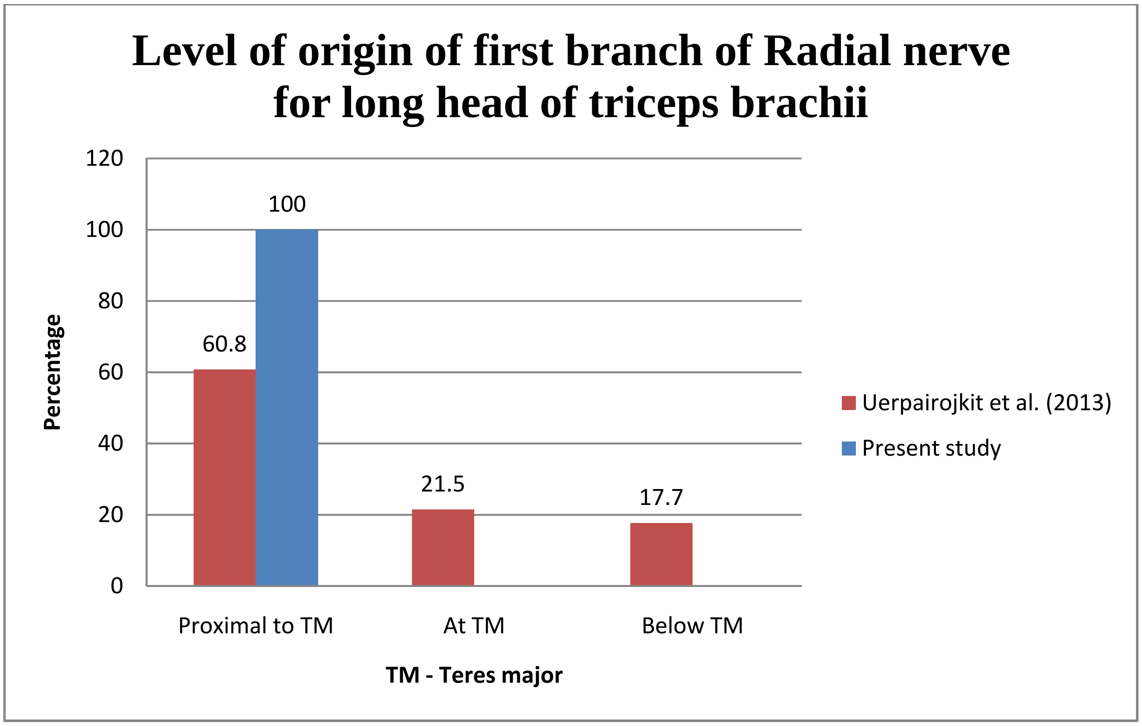


Chart 10. Level of origin of first branch of Radial nerve for long head of triceps brachii

The nerve for long head is a suitable branch to restore the functionality of deltoid muscle in patients with C5–C6 root injury. The nerve for long head is the first constant branch from radial nerve to triceps. Studies have shown that if the long head branch was transferred, the combined actions of the remaining two heads of triceps will be sufficient to perform elbow extension. Travill (69) in his study had established the fact that in elbow extension, long head played a minimal role compared to the other two heads. Branch for long head is a suitable branch for transfer because of its constant point of origin from radial nerve. Axillary nerve lies close to branch for long head of triceps, and hence the latter could be transferred to anterior branch of axillary nerve without a nerve graft. Knowing the distance of origin of branch for long head from teres major will help in identifying the branch and anastomosing it to axillary nerve.

Innervation of medial head of triceps brachii

Uerpairojkit et al. (58), in their study of 79 arms found single branch for medial head in 65 arms (82%) and double innervation in 14 arms (18%). Meshal et al. (60)in their study found that medial head of triceps had a single branch in 22 cases (88%) and double innervation in 3 cases (12%).

In the present study, single innervation of medial head was seen in 26 arms (93%) and double innervation in 2 arms (7%). This was in accordance with the findings of Uerpairojkit et al. (58) (Chart 11)

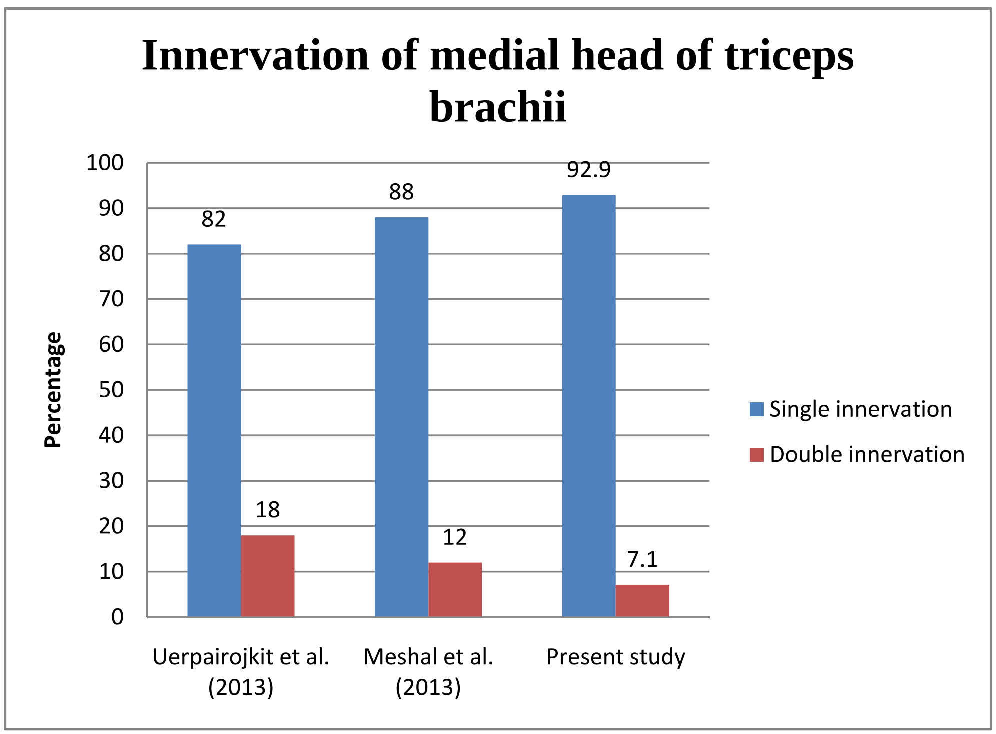


Chart 11. Innervation of medial head of triceps brachii

The branch for medial head is easy to expose as it lies in the interval between lateral and long heads. Obtaining the branch for medial head does not require intramuscular dissection because of its increased length outside the muscle (61). In case medial head has double innervation, one of its branches can be used for transfer, without affecting its action. The ease of identification of branch to medial head of triceps and its added length make it an appropriate donor.

Pattern of branching

The patterns of nerve branching of triceps was classified as types A, B, C, and D depending on number of branches. Uerpairojkit et al. (58) found the following patterns of branching in their study - 5 branches (type A) in 21 arms (26.6%), 4 (type B) in 38 arms (48.1%), 3 (type C) in 17 arms (21.5%), and 2 (type D) in 3 arms (3.8%).

In the present study, the patterns seen were - 5 branches (type A) in 1 arm (3.6%), 4 branches (type B) in 3 arms (10.7%), 3 branches (type C) in 22 arms (78.6%), and 2 branches (type D) in 2 arms (7.1%). Type B2 – 6th pattern and type D – 2nd pattern were two new patterns seen in the present study. Type C was the most common pattern seen in the present study as compared to type B in the study by Uerpairojkit et al. (58). The least common pattern is type A in the present study and type D in the study by Uerpairojkit et al. (58) (Table 15).

Table 15. Patterns of Nerve Branching to Triceps Brachii

Types of Patterns	Uerpairojkit et al. (2013) (n = 79)		Present study (n = 28)	
	Thai Population		Indian Population	
	No. of arms	Percentage (%)	No. of arms	Percentage (%)
Type A	21	26.6	1	3.6
Type B1	17	21.5	1	3.6
Type B2	22	27.8	1	3.6
Type B2 (6th Pattern)	-	-	1	3.6
Type C1	2	2.5	0	0
Type C2	7	8.9	0	0
Type C3	5	6.3	22	78.6
Type C variations	2	2.5	0	0
Type D	3	3.8	0	0
Type D (2nd Pattern)	-	-	2	7.1

A study of the pattern of branching of the radial nerve branches to triceps can help to identify the most appropriate branch for nerve transfer, thus improving the outcome of the treatment of upper brachial plexus injuries without causing donor muscle weakness

8.CONCLUSIONS

Understanding the topographical anatomy of radial nerve in arm with the help of certain external landmarks (surface landmarks) can help to locate radial nerve before exploratory surgery is undertaken in the treatment of humeral fractures.

. The following conclusions were drawn.

1. The mean acromion-transepicondylar distance was found to be 268.1 ± 28 mm.
2. The mean distance between tip of acromion and point where radial nerve reached spiral groove was found to be 109.4 ± 24.4 mm (40.6 % of the acromion-transepicondylar distance).
3. The mean distance between the tip of acromion and point where radial nerve left spiral groove was found to be 146.8± 25.7 mm (54.7% of the acromion-transepicondylar distance).
4. The mean distance between tip of acromion and the site where radial nerve pierced lateral intermuscular septum was found to be 180.2 ± 30.3 mm (67% of the acromion-transepicondylar distance).
5. The mean distance from lateral humeral epicondyle to superior margin of the spiral groove was found to be 188.4 ± 13.6mm.
6. The mean distance from lateral humeral epicondyle to inferior margin of the spiral groove was found to be 127.4 ± 17.1 mm.
7. The mean length of spiral groove was found to be 62.4±15.7mm.
8. The site of termination of radial nerve into its terminal branches was above transepicondylar line in 85.7%, at transepicondylar line in none and below transepicondylar line in 14.3% of upper extremities.

Certain anatomical markings like distal part of deltoid tuberosity, point of confluence and lateral border of aponeurosis of triceps are easily identifiable intraoperatively. The following conclusions will help to avoid intraoperative radial nerve injury

9. The mean distance between radial nerve and distal part of deltoid tuberosity at posterior midline of humerus was found to be 37.6 ± 13 mm.
10. The mean distance from point of confluence to radial nerve was 39.7± 11.8mm.
11. The radial nerve was found to pass at a distance of 12 – 19.5 mm from lateral border of triceps aponeurosis.

    The branches of triceps can be anastomosed to axillary nerve in cases of C5-C6 root injuries for restoring the function of deltoid muscle. Knowing the location of these branches and the pattern of branching will help in nerve transfer procedures.

12. Each head of triceps brachii had a mean number of 1.1 nerve branches innervating it.
13. The mean distance from inferior end of deltoid to origin of the branch for long head was 62.8 ± 16.1mm.
14. The mean distance from inferior end of deltoid to entry point of the branch for long head was 48.6 ± 15.4mm.
15. The mean distance from inferior end of deltoid to origin of the branch for lateral head was 56.1 ± 15.8mm.
16. The mean distance from inferior end of deltoid to entry point of the branch for lateral head was 26.7 ± 11.7mm.

17. The mean distance from inferior end of deltoid to origin of the branch for medial head was 49.3 ± 19.1mm.
18. The mean distance from inferior end of deltoid to entry point of the branch for medial head was 27.8 ± 16 mm.
19. The mean distance from the origin of branch for long head of triceps and inferior border of teres major was 9.9 ± 5.5 mm.
20. The mean distance from the origin of branch for lateral head of triceps and inferior border of teres major was 10.0 ± 7.3 mm.
21. The mean distance from the origin of branch for medial head and inferior border of teres major was 16.7 ± 10.8 mm.
22. The first branch from radial nerve to triceps was the nerve to long head.
23. The mean distance of origin of first branch of radial nerve to triceps and inferior border of teres major was 10.4 ± 6.6 mm.
24. The medial head had single innervation in 92.9% and double innervation in 7.1% of upper extremities.
25. The most common pattern of nerve branching seen was Type C3 (78.6%).
26. The least common pattern of nerve branching seen was Type A (3.6%).
27. Two new patterns of nerve branching seen in the present study were Type B2 (6^{th} pattern) and Type D (2^{nd} pattern).
28. The most appropriate branch for nerve transfer procedure will be the branch to long head because of its proximity to anterior branch of axillary nerve.

9. LIMITATIONS

1. The present study was done on formalin embalmed upper extremities, where tissues are hard and fixed. In the actual surgical setting, the tissues are supple and soft. Further studies in fresh cadaveric specimens would be needed so that anatomic data derived from such studies can be applied to the clinical setting to prevent intraoperative injury to radial nerve.

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OFFICE OF RESEARCH
INSTITUTIONAL REVIEW BOARD (IRB)
CHRISTIAN MEDICAL COLLEGE, VELLORE, INDIA.

Dr. B.J. Prashantham, M.A., M.A., Dr. Min (Clinical)
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Dr. Alfred Job Daniel, D Ortho, MS Ortho, DNB Ortho
Chairperson, Research Committee & Principal

Dr. Nihal Thomas,
MD., MNAMS., DNB (Endo), FRACP (Endo), FRCP (Edin), FRCP (Glasg)
Deputy Chairperson
Secretary, Ethics Committee, IRB
Additional Vice Principal (Research)

February 13, 2015

Dr. P. Mythraeyee
PG Demonstrator
Department of Anatomy
Christian Medical College, Vellore 632 002

Sub: **Fluid Research Grant Project:**
Topographical Anatomy of Radial nerve and its Muscular Branches to triceps.
Dr. P. Mythraeyee, Dr. Bina Isaac, Anatomy, Dr. Prasanna Samuel Premkumar, Biostatistics, CMC, Vellore.

Ref: IRB Min No: 9241 [OBSERVE] dated 12.01.2015

Dear Dr. P. Mythraeyee,

I enclose the following documents:-

1. Institutional Review Board approval 2. Agreement

Could you please sign the agreement and send it to Dr. Nihal Thomas, Addl. Vice Principal (Research), so that the grant money can be released.

With best wishes,

Dr. Nihal Thomas
Secretary (Ethics Committee)
Institutional Review Board

Dr. NIHAL THOMAS
MD.,MNAMS.,DNB(Endo),FRACP(Endo),FRCP(Edin),FRCP(Glasg)
SECRETARY - (ETHICS COMMITTEE)
Institutional Review Board,
Christian Medical College, Vellore - 632 002.

Cc: Dr. Bina Isaac, Anatomy, CMC, Vellore.

Ethics Committee Blue, Office of Research, 1st Floor, Carman Block, Christian Medical College, Vellore, Tamil Nadu 632 002.
Tel : 0416 - 2284294, 2284202 Fax : 0416 - 2262788, 2284481 E-mail : research@cmcvellore.ac.in

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Dear Dr. P. Mythraeyee,

The Institutional Review Board (Blue, Research and Ethics Committee) of the Christian Medical College, Vellore, reviewed and discussed your project entitled "Topographical Anatomy of Radial nerve and its Muscular Branches to triceps." on January 12th 2015.

The Committees reviewed the following documents:

1. IRB Application format
2. Curriculum Vitae' of Drs. P. Mythraeyee, Bina Isaac, Prasanna Samuel Premkumar
3. No of documents 1 – 2

The following Institutional Review Board (Blue, Research & Ethics Committee) members were present at the meeting held on January 12th 2015 in the CREST/SACN Conference Room, Christian Medical College, Bagayam, Vellore 632002.

Name	Qualification	Designation	Other Affiliations
Dr. Inian Samarasam	MS, FRCS, FRACS	Professor,Surgery, CMC	Internal, Clinician
Dr. Anand Zachariah	MBBS, PhD	Professor, Medicine, CMC	Internal, Clinician

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MD., MNAMS., DNB (Endo), FRACP (Endo), FRCP (Edin), FRCP (Glasg)
Deputy Chairperson
Secretary, Ethics Committee, IRB
Additional Vice Principal (Research)

Dr. Mathew Joseph	MBBS, MCH	Professor, Neurosurgery, CMC	Internal, Clinician
Dr. Niranjan Thomas	DCH, MD, DNB (Paediatrics)	Professor, Neonatology,CMC	Internal, Clinician
Dr. Jacob John	MBBS, MD	Associate Professor, Community health	Internal, Clinician
Dr. Vivek Mathew	MD (Gen. Med.) D.M (Neuro)Dip. NB (Neuro)	Professor, Neurology, CMC	Internal, Clinician
Dr. Chandrasingh	MS, MCH, DMB	Professor, Urology, CMC.	Internal, Clinician
Dr. Anup Ramachandran	Ph. D	The Wellcome Trust Research Laboratory Gastrointestinal Sciences, CMC	Internal, Basic Medical Scientist
Dr. Simon Pavamani	MBBS, MD,	Professor, Radiotherapy, CMC.	Internal, Clinician
Dr. Visalakshi. J	MPH, PhD	Lecturer, Dept. of Biostatistics, CMC.	Internal, Statistician
Dr. T. Balamugesh	MBBS, MD(Int Med), DM, FCCP (USA)	Professor, Pulmonary Medicine, CMC	Internal, Clinician
Dr. B. J. Prashantham	MA(Counseling Psychology), MA(Theology), Dr. Min(Clinical Counselling)	Chairperson, Ethics Committee, IRB. Director, Christian Counseling Centre, Vellore	External, Social Scientist
Mrs. Pattabiraman	B. Sc, DSSA	Social Worker, Vellore	External, Lay Person
Dr. Denise H. Fleming	B. Sc (Hons), PhD	Honorary Professor, Clinical Pharmacology, CMC	Internal, Scientist & Pharmacologist
Dr. Anuradha Rose	MBBS, MD	Assistant Professor, Community Health	Internal, Clinician
Mrs. Emily Daniel	MSc Nursing	Professor, Medical Surgical Nursing	Internal, Nurse

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Deputy Chairperson
Secretary, Ethics Committee, IRB
Additional Vice Principal (Research)

Mr. C. Sampath	BSc, BL	Legal Expert, Vellore	External, Legal Expert
Rev. Joseph Devaraj	B. Sc, BD	Chaplaincy Department, CMC	Internal, Social Scientist
Dr. Nihal Thomas	MD, MNAMS, DNB(Endo), FRACP(Endo) FRCP(Edin) FRCP (Glasg)	Professor & Head, Endocrinology. Additional Vice Principal (Research), Deputy Chairperson, IRB, Member Secretary (Ethics Committee),IRB	Internal, Clinician

We approve the project to be conducted as presented.

The Institutional Ethics Committee expects to be informed about the progress of the project, any **adverse events** occurring in the course of the project, any **amendments in the protocol and the patient information / informed consent**. On completion of t'he study you are expected to submit a copy of the **final report**. Respective forms can be downloaded from the following link: http://172.16.11.136/Research/IRB_Polices.html in the CMC Intranet and in the CMC website link address: http://www.cmch-vellore.edu/static/research/Index.html.

Fluid Grant Allocation:

A sum of 11,900/- INR (Rupees Eleven Thousand Nine Hundred only) will be granted for 2 years.

Yours sincerely

Dr. Nihal Thomas
Secretary (Ethics Committee)
Institutional Review Board

DR. NIHAL THOMAS
MD.,MNAMS.,DNB(Endo),FRACP(Endo),FRCP(Edin),FRCP(Glasg)
SECRETARY - (ETHICS COMMITTEE)
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Cc: Dr. Bina Isaac, Anatomy, CMC, Vellore.

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PROFORMA

Disc number of cadaver:

Sex of cadaver:

Side of limb:

Measurements to trace the course of the Radial Nerve

Parameter	Mean distance (mm)	SD (mm)	Range (mm)
Distance between the tip of the acromion and the transepicondylar line			
Distance between the tip of the acromion where the radial nerve reached the radial groove			
Distance between the tip of the acromion and where the radial nerve left the radial groove			
Distance between the tip of the acromion and the location where the radial nerve pierced the lateral intermuscular septum			
Distance between the transepicondylar line and the location where the radial nerve divided into the superficial and deep branches			
Distance from distal part of deltoid tuberosity to radial nerve at posterior midline of humerus			
Distance between the Point of Confluence and the Radial Nerve			

The Different Patterns of the Nerve Branches to Triceps Brachii

Types of Patterns	No. of arms	Percentage (%)
Type A		
Type B		
Type C		
Type D		

Measurements of the Radial Nerve in Relation to Triceps Aponeurosis

Parameter	Mean distance (mm)	SD (mm)	Range (mm)
A: Shortest distance nerve to lateral epicondyle			
B: Lateral epicondyle to inferior margin of groove			
C: Lateral epicondyle to superior margin of groove			
D: Aponeurosis to nerve 1/4			
E: Aponeurosis to nerve 2/4			
F: Aponeurosis to nerve 3/4			
G: Aponeurosis to nerve 4/4			
H: Length of radial groove			

The Number and Location of Origin and Attachment of the Branches to each head of Triceps Brachii

Number of branches 1 2 3 4	
<u>Origin of branches</u> Location Proximal to the radial groove On the radial groove Proximal and on the radial groove	
<u>Distance of origin of branch</u> From the inferior margin of teres major From inferior end of deltoid	
<u>Distance of attachment of branch</u> From inferior end of deltoid	